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Lead and Zinc Availability—Domestic

A Minerals Availability Program Appraisal

By Catherine C. Kilgore, Sylvia J. Arbelbide, and Audrey A. Soja

UNITED STATES DEPARTMENT OF THE INTERIOR

(United States. Bureau of Mines)

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UNITED STATES DEPARTMENT OF THE INTERIOR
William P. Clark, Secretary

BUREAU OF MINES
Robert C. Horton, Director

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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PREFACE

The Bureau of Mines Minerals Availability Program is assessing the worldwide availability of nonfuel minerals. It identifies, collects, compiles, and evaluates information on active and developing mines, explored deposits, and mineral processing plants worldwide. Objectives are to classify domestic and foreign resources; to identify, by cost evaluation, resources that are reserves; and to prepare analyses of mineral availabilities.

This report is part of a continuing series of reports that analyze the availability of minerals from domestic and foreign sources and the factors affecting availability. Questions about these reports should be addressed to Chief, Division of Minerals Availability, Bureau of Mines, 2401 E St., NW., Washington, DC 20241.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

km	kilometer
lb	pound
ltu	long ton unit
lb/t	pound per metric ton
m	meter
tr oz/ton	troy ounce per short ton
pct	percent
sq km	square kilometer
t	metric ton
t/yr	metric ton per year
ton	short ton
ton/t	short ton per metric ton
tr oz	troy ounce
wt pct	weight percent
yr	year

LEAD AND ZINC AVAILABILITY—DOMESTIC

A Minerals Availability Program Appraisal

By Catherine C. Kilgore,[1] Sylvia J. Arbelbide,[1] and Audrey A. Soja[2]

ABSTRACT

The Bureau of Mines investigated the availability of lead and zinc from 104 domestic mines and deposits. Fourteen primary lead and fifty-three primary zinc operations with in situ demonstrated resources containing 27.3 million metric tons (t) of lead and 53 million t of zinc were subsequently evaluated.

Potentially 17.5 million t of lead and 2.4 million t of byproduct zinc could be recovered from 14 primary lead operations. Economic evaluations performed in constant January 1982 dollars determined a long-run total cost per pound of recoverable commodity. Including a 15-pct discounted-cash-flow rate of return (DCFROR), 59 pct of primary lead was potentially available at or below $0.32 per pound of lead.

Potentially 40 million t of zinc and 5.6 million t of byproduct lead could be recovered from 53 primary zinc operations. Ninety percent of the recoverable zinc is potentially available from currently nonproducing mines and deposits, and a weighted average of their long-run total costs was determined at $0.98 per pound of zinc. At a breakeven (0-pct) DCFROR, these nonproducing operations had a weighted average long-run total cost of $0.58 per pound of zinc.

Sensitivity analyses illustrated that operations that recover byproducts were most sensitive to fluctuating metal prices, producing operations were more sensitive to increased smelter treatment charges, and nonproducing operations were impacted most by the DCFROR.

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INTRODUCTION

The purpose of this report is to identify and define the demonstrated domestic lead and zinc resources and evaluate the potential production from these resources. The Bureau investigated the availability of lead and zinc from 104 domestic mines and deposits, and subsequently evaluated the engineering and economic availability of lead and zinc from 67 of the mines and deposits. A complete listing of the 67 mines and deposits that were evaluated and their ownership is given in appendix A.

The procedure for this evaluation was to identify recoverable resources and the engineering and economic parameters that would affect proposed production from the deposits selected for evaluation. Capital investments and operating costs (direct and indirect) for the appropriate mining and beneficiation methods were estimated, transportation costs and standardized postmill processing charges were assessed, and a cost evaluation for each deposit was performed. Finally, the individual deposit evaluations were aggregated to show potential lead and zinc availability at various commodity prices.

Of the initial 104 deposits investigated, 37 were excluded from evaluation because their resource tonnages were reported as inferred rather than demonstrated, or because the demonstrated resources as of January 1, 1981, contained less than 50,000 t of in situ primary lead or zinc.[3] Deposits excluded from evaluation are listed in appendix B.

The top 15 domestic producers of lead and/or zinc in 1981 were included in this evaluation with the exception of the Austinville and Ivanhoe mines in Virginia, which are near depletion (*1-2*).[4] As of the 1982 evaluation date, there were five producing mines with demonstrated resources containing less than 50,000 t of in situ lead or zinc that were included because their resources were not near depletion. Three of these mines were included because they have small annual production rates and estimated production lives of nearly 20 yr. The other two operations have historically estimated close to the same resource tonnage every year. Mines such as these two, with small resource tonnages for lead and zinc, may produce precious metals as their primary product, but also produce significant quantities of lead and/or zinc. These mines may define a resource tonnage sufficient for only a few years of production at current mining rates for various reasons, such as complex geological conditions and high exploration costs.

The methodologies employed to define and evaluate engineering and economic parameters for each individual mine or deposit are described in the following section.

METHODOLOGY

The Minerals Availability Program is developing a continuously evolving methodology for the analysis of long-run mineral resource availability. An integral part of this system is the Bureau's Supply Analysis Model (SAM) (*3*). This interactive computer system is an effective mathematical tool for analyzing the effects of various parameters upon the economic availability of domestic and international resources.

For each operation included in this evaluation, capital expenditures were calculated for exploration, acquisition, development, mine and plant equipment, and for constructing and equipping the mill. The capital expenditures for the different mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, infrastructure, and working capital. Infrastructure is a broad category that includes costs for access and haulage facilities, ports, water facilities, power supply, and personnel accommodations. Working capital is a revolving cash fund required for operating expenses such as labor, supplies, insurance, and taxes.

The initial capital costs for producing or past producing mines and developed deposits have been depreciated according to when the investment was actually made, and the undepreciated portion was treated as a capital investment in 1982, the first year of the evaluation. Reinvestments will vary according to capacity, length of production life, and age of the facilities.

The total operating cost of a mining project is a combination of direct and indirect costs. Direct operating costs include operating and maintenance labor and supplies, supervision, payroll overhead, insurance, local taxation, and utilities. The indirect operating costs include technical and clerical labor, administrative costs, maintenance of facilities, and research.

After production parameters and costs for the development of domestic lead and zinc deposits were established, the SAM was used to perform various economic evaluations pertaining to the availability of domestic lead and zinc. The SAM system is a comprehensive economic evaluation simulator that is used to determine the constant-dollar long-run price at which the primary commodity must be sold (after smelting-refining) to recover all costs of production, including a prespecified discounted-cash-flow rate of return (DCFROR) on investment. The DCFROR is defined as the rate that makes the present value of all current and future revenues equal to the present value of all current and future costs of production. For this study, a constant rate of return on investment of 15 pct was specified. This rate was considered sufficient to attract new capital to the industry.

The SAM system contains a separate tax records file for each State, which includes all the relevant tax parameters under which a mining firm would operate. These tax parameters are applied to each mineral deposit under evaluation with the implicit assumption that each deposit represents a separate corporate entity. Other costs in the analysis include standard deductibles such as depreciation, depletion, deferred expenses, investment tax credits, and tax loss carry forwards. The SAM system also contains a separate file of economic indexes to allow for updating of all cost estimates for both producing and nonproducing deposits.

Price tables are maintained for all primary commodities, byproducts, and coproducts that will be relevant to the availability analyses, and all byproducts recovered in the analyses are considered to be marketable. The commodity prices used in this study are shown in table 1.

Detailed cash-flow analyses are generated with the SAM system for each preproduction and production year of a mine or deposit beginning with the initial year of analysis, 1982. Upon completion of the individual analysis for each deposit, all properties were simultaneously analyzed and aggregated into an availability curve.

The availability of the primary product recoverable from a deposit is presented graphically, and in the text of this evaluation, as a function of the total cost of production associated with that deposit. Availability curves are con-

[3]The term "contained" refers to the actual quantity of the element present within the ore, concentrate, or final product, irrespective of its form. The term "in situ" denotes resources existing in the ground. Thus, the mines or deposits excluded from this study contained less than 50,000 t of the element in various mineral forms in demonstrated resources. In situ grade refers to the percentage of lead or zinc contained in the deposit. Demonstrated and inferred resources are defined in the "Domestic Resources" section.

[4]Italicized numbers in parentheses refer to items in the list of references preceding the appendixes.

Table 1.—Commodity prices used in economic evaluations

Commodity		Price, January 1982
Barite	per ton	$105.00
Cadmium	per lb	1.40
Copper	per lb	.79
Fluorspar	per t	165.00
Gold	per tr oz	384 12
Iron (pellets)	per ltu	.81
Lead	per lb	.30
Limestone	per t	4.13
Silver	per tr oz	8.03
Zinc	per lb	.42

structed as aggregations of the total amount of commodity potentially available from each of the evaluated operations, ordered from the deposits having the lowest average total cost per unit of production to those having the highest. The potential availability of the primary commodity at a price can be seen by comparing, for example, the expected long-run constant-dollar market price to the average total cost values shown on the availability curves. The total recoverable tonnage potentially available at or below this price-cost value can be read directly from the total availability curve. Annual availability curves were also constructed to account for the time lags involved in achieving the total production potential. These curves are simply the total availability of domestic lead or zinc in any given year, based on the development and production schedules assumed for each deposit.

Certain assumptions are inherent in these curves. First, all deposits will produce at full design capacity throughout the productive life of the deposit. Second, each operation will be able to sell all of its output at the determined total cost and obtain at least the minimum specified rate of return. Third, all preproduction development of all nonproducing deposits began in January 1982.

DOMESTIC LEAD AND ZINC INDUSTRY

The availability of domestic lead and zinc as presented in this report is affected by a number of factors currently influencing the lead and zinc industries in general. A brief overview of the domestic industry is presented in this section.

DOMESTIC LEAD INDUSTRY

The United States is the largest refiner and consumer of lead in the world. Average primary (refined) production of lead between 1977 and 1981 was reported at 549,000 t/yr, and average domestic mine production levels over the same period were reported at 94 pct of this level, 518,000 t of contained lead per year (*2*). Many of the domestic lead mines produce competitively in the world market, particularly the highly mechanized Missouri operations, which produce most of the domestic concentrates. However, the United States is still a net importer of lead concentrates and refined lead, and average consumption levels between 1977 and 1981 of nearly 1.3 million t of contained lead in all forms have resulted in an average net import reliance of about 4 pct (*4-5*).

The cost of meeting environmental regulations may have been a significant factor in recent closures of domestic smelter facilities for both primary and secondary lead. Major capital expenditures have been required for most producers to attempt to meet the regulations of the Clean Air and Clean Water Acts, as well as the numerous regulations promulgated by the Occupational Safety and Health Administration (OSHA). Some of the facilities have closed down temporarily, or even permanently, because they cannot meet the numerous regulations, and heavy fines are often imposed for violations (*6-8*).

SECONDARY PRODUCTION OF LEAD

The United States has a well-developed secondary metal industry that included about 58 major operating plants in 1981. These plants recovered approximately 641,000 t of contained lead from scrap, which represented 55 pct of total reported lead consumption. Between 1977 and 1981, secondary production of lead from scrap has averaged 729,000 t/yr, representing 56 pct of reported consumption (*2*).

With consumption declining in dissipative uses such a tetraethyl lead (TEL) in gasoline, more lead may be consumed in products that are easily recyclable and, as a result, scrap lead could become more readily available and provide a strong incentive for increased secondary production (*6*). The secondary lead industry currently depends heavily on the battery industry as both a source of feed and as a market outlet.

Secondary producers compete with primary producers because refined secondary lead may be substituted completely for primary lead in most applications. Technically, 58 pct of all primary lead produced may potentially be recycled (*6*). The similarity of the two products allows for a high degree of competition in determining the level of the U.S. producer price for lead.

The recent trend of low primary producer prices effectively narrowed the gap between primary and secondary producer prices and cut into the profit margins of secondary producers. With the relatively high scrap prices, production levels have declined, resulting in excess processing capacity. The industry estimates that between 70 and 75 pct of the 1.1-million-t/yr secondary scrap capacity is currently being utilized (*6*).

Although there is sufficient domestic smelting capacity available, the United States is a large exporter of scrap lead for the secondary production industry. Foreign secondary smelters have been outbidding U.S. smelters for the lead scrap in recent years, due in part to higher capital, operating, and environmental costs borne by the domestic smelters. There have been no long-term, industry-wide, physical raw material shortages, however. If all U.S.-generated scrap were recycled domestically, refined imports could potentially be halved and U.S. self-sufficiency could approach 100 pct (*7*).

As illustrated in table 2, total domestic production of secondary lead is greater than primary mine production. However, since 1979, secondary lead production levels have dropped as a number of economic difficulties have plagued the secondary lead industry. The most significant difficulty is the continuing shortage of available scrap at acceptable prices.

Table. 2.—Historic production of lead

(Thousand metric tons of contained lead)

Production	1977	1978	1979	1980	1981
Mine	537	530	526	550	446
Primary (refined)[1]	552	568	578	548	498
Secondary	758	769	801	676	641
Secondary, percent of total contained lead from primary and secondary production	58	57	58	55	56

[1] Refined lead plus lead content of antimonial lead, and foreign ores imported for consumption.

Source: Reference 2.

DOMESTIC ZINC INDUSTRY

Domestic zinc mine-mill capacity has declined over the years, and the U.S. share of concentrate production in the world market has fallen to barely 5 pct (*1*). The declining importance of the domestic zinc mining industry results in part from low ore grades and low byproduct revenues from many domestic zinc operations, which result in some of the highest production costs in the world (*7*).

The number of domestic zinc postmill processing closures over the years has resulted in a drop in self-sufficiency in metal production, and an increase in the domestic reliance on imported zinc products. Foreign government aid programs that stimulate smelter construction have resulted in severe competition from foreign smelters, and the trend towards importing refined products has grown over the years (*7-8*).

Environmental costs have only been one of several factors contributing to recent closures in the zinc industry. Outmoded technology, lack of feed sources, and the high cost of energy and labor have also impacted the domestic industry. Smelter facilities built in the early 1900's have predominated the domestic industry, and a number of them have required extensive modernization, or complete replacement in recent years. Along with the high cost of operating and/or modernizing the older, and often energy-intensive smelter facilities, the relatively low domestic zinc grades and resulting decline in production have had the greatest negative economic impact on the domestic zinc industry (*7-9*).

Mine production rates for zinc between 1977 and 1981 have averaged 321,000 t/yr, while apparent domestic consumption levels have been significantly larger, at 1.3 million t/yr of contained zinc in all usage forms (*1*). This difference has resulted in an average net import reliance of 62 pct during this period (*10-11*).

Table 3 lists the imports, exports, and consumption levels for various forms of zinc for 1980 and 1981. As shown in the table, the United States imported nearly twice as much zinc metal in the form of blocks, pigs, and slab as in zinc ore and concentrate. Imports of zinc ore and concentrates were mainly from Canada, Peru, Mexico, and Honduras. Primary suppliers of the metal products were Canada, Spain, Mexico, Australia, Peru, Finland, and Zaire.

Table 3.—Zinc import, export, and consumption figures for the years 1980 and 1981

(Thousand metric tons of contained zinc)

	1980	1981
Imports:		
Ore and concentrates:		
Canada	110	180
Honduras	7	4
Mexico	14	21
Peru	40	29
Other	11	12
Total	182	246
Metal (blocks, pigs, slab):		
Australia	25	26
Canada	280	309
Finland	18	29
Mexico	24	15
Peru	4	43
Spain	11	29
Zaire	NAp	29
Other	48	132
Total	410	612
Exports:		
Slab	.3	.3
Waste and scrap	30	30
Ore and concentrate	54	54
Total	84	85
Apparent consumption:		
Slab	811	834
Ores	59	61
Zinc scrap	133	149
Other scrap[1]	139	139
Total	1,142	1,184

NAp Not applicable.

[1] Other scrap includes zinc contained in copper, aluminum, and magnesia-based scrap.

NOTE.—Data may not add to totals shown because of independent rounding.
Source: Reference 1.

CLOSURES IN LEAD AND ZINC INDUSTRY

As the recent trend of increasing production costs and declining metal prices continued, domestic mine production also declined. Domestic smelters and refineries have had to buy foreign concentrates in order to keep operating, as the trend of reduced domestic concentrate production, particularly zinc, has continued (*8*). Operations in many countries are able to produce and export the final products, such as slab zinc, at prices below their U.S. counterparts, who have to add the cost of importing foreign concentrates to their cost of processing. The shortage of domestic zinc concentrates, along with the already high capital and operating costs that plague the domestic smelters and refineries, have resulted in a number of cutbacks in production and permanent closures in the industry.

The Bunker Hill lead-zinc-silver mining and metallurgical complex in Kellogg, ID, closed at the end of 1981, typified the problems facing the domestic industry. The Bunker Hill smelter and refinery operations annually accounted for approximately 113,000 t of primary lead and 91,000 t of refined zinc, and in 1980 its production represented 20 and 21 pct of the domestic refined lead and zinc, respectively (*8*). In addition, the Bunker Hill facilities annually produced between 10 and 12 million tr oz of silver (23 pct of the domestic primary silver output for 1980), over 1 million lb of cadmium, and a variety of other byproducts. A portion of these metals were derived from Bunker Hill's own mines; however, portions of the output were derived from concentrates purchased from or tolled for other parties, both domestic and foreign (*8, 12*). Bunker Hill has cited labor disputes, low metals prices, and environmental costs as reasons for its closure (*13*).

The Bunker Hill smelter and refinery facilities have not been dismantled to date, and it could resume operation with minimum capital expenditures, possibly in less than a year. For these reasons, the capacity is considered to be on a standby basis and is potentially available if needed. However, the facility was closed as of the study date and not utilized for this evaluation.

Although many mines and smelting and refining operations have announced plans to cut back on production or close indefinitely, changes in the economy, particularly improvements in metals prices, could provide the incentive to bring a number of them back into operation. As mining operations return to or increase production, or as new operations start, the smelting industry could also begin to pick up. For example, in 1979 the Monaca zinc plant in Pennsylvania was closed indefinitely (*14*). However, bringing the new Pierrepont deposit into production in 1982 supplied the ore concentrates and the incentive to initiate the $2 million reactivation of the Monaca plant (*15-16*).

DOMESTIC RESOURCES

Selection of mines and deposits for this study was limited to known deposits with demonstrated lead and zinc resources containing at least 50,000 t of in situ primary lead or zinc. Demonstrated resources are defined as the measured plus indicated portion of identified tonnages (*17*). The in situ contained lead and zinc values are derived from these tonnages. For this evaluation, demonstrated resources are not restricted by economic status and may include resources that are currently economic, marginally economic, and even subeconomic.

As mentioned previously, 37 of the 104 mines and deposits originally analyzed were excluded from this study because their resource tonnages were reported as inferred rather than demonstrated, or because the demonstrated resources were very small, with less than 50,000 t of contained primary lead or zinc metal. These 37 mines and deposits contained approximately 200,000 t of primary lead and 1.7 million t of primary zinc.

Mines and deposits that have resources containing both lead and zinc were classified under the primary commodity that generated the larger percent of revenues at January 1982 prices. Thus, mines often considered primary lead producers, such as the Black Cloud mine near Leadville, CO, may have generated higher zinc revenues than lead revenues and can be found classified as primary zinc mines in this evaluation. In some cases, the revenues generated by another commodity, such as gold, silver, or copper, were larger than those revenues generated by the lead or zinc, but the operation was classified according to which of the two studied commodities, lead or zinc, generated the greater amount of revenues. Figure 1 shows the locations of the mines and deposits classified as primary lead operations, while figure 2 shows the primary zinc operations.

PRIMARY LEAD RESOURCES

Demonstrated resources for the 14 mines and deposits evaluated as primary lead operations for this study total 315.3 million t with a weighted average in situ grade of 6.46 pct. These in situ resources contain 20.4 million t of primary lead and approximately 3.8 million t of byproduct zinc. Table 4 is a listing, by property, of the resource tonnages and in situ grades for the primary lead operations.

In addition to the 20.4 million t of primary lead, 6.9 million t of lead is contained in mines and deposits that have been classified as primary zinc operations. This results in a U.S. total of 27.3 million t of contained lead from all operations recovering lead for this evaluation.

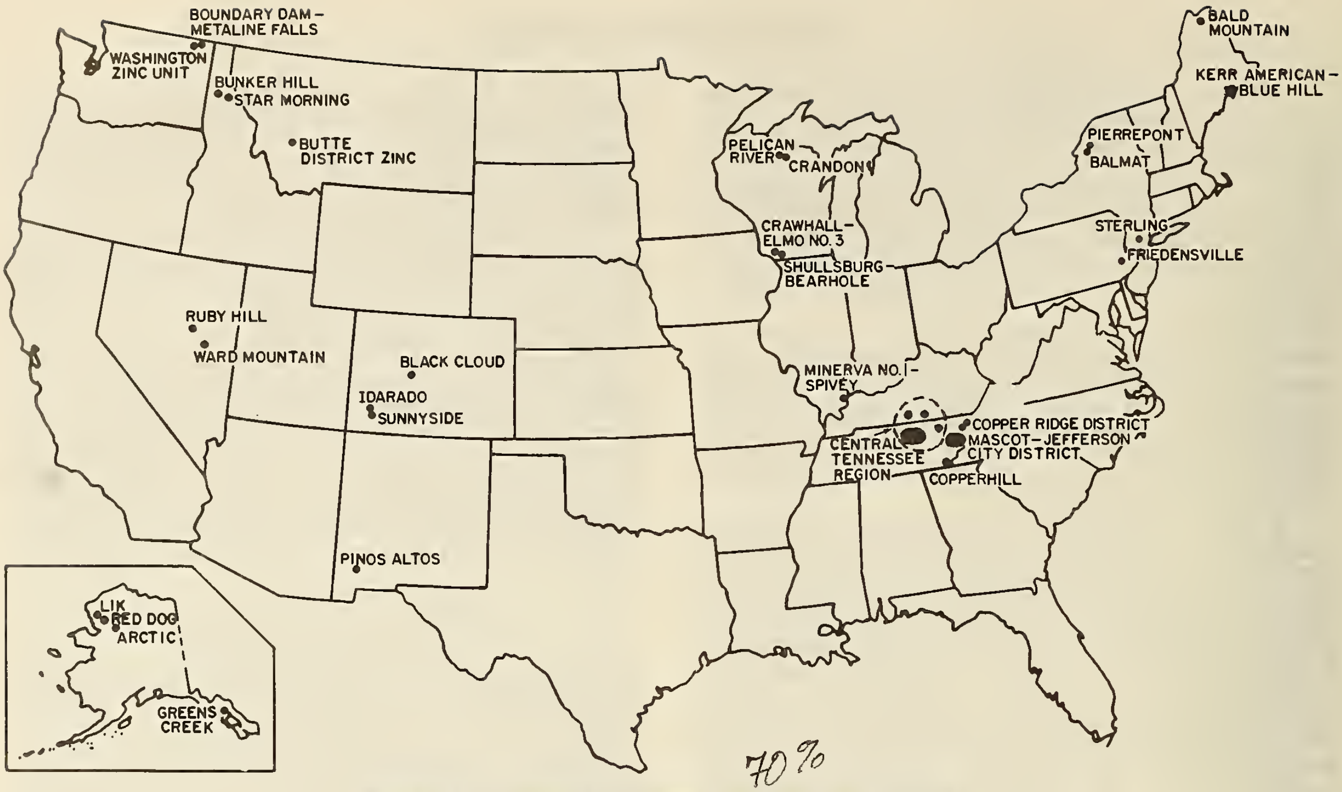
As illustrated in table 5, approximately 89 pct (18.1 million t) of the lead contained in demonstrated resources is potentially available from the nine producing primary lead operations. The remaining five mines and deposits contain 2.3 million t of lead. Total potentially recoverable[5] lead from the 14 primary operations is 17.5 million t of lead with 2.4 million t of byproduct zinc. In addition to primary lead resources, 5.6 million t of lead is potentially recoverable as a byproduct from the primary zinc resources.

DOMESTIC LEAD CAPACITY

After the lead concentrate leaves ,the mill, it first goes to a smelter and then to a refinery. There are currently five operating primary lead smelters in the United States, and three of these facilities also include refineries. The other two lead smelter facilities handle concentrates on a custom basis and then ship the concentrates to a fourth refinery at Omaha, NE. The locations and capacities of U.S. and Canadian smelters and refineries utilized for this evaluation are shown on figure 3.

[5]Recoverable is used to describe the amount of lead or zinc contained in the final product. It was assumed that all lead would be processed to lead bullion, and zinc would be processed to zinc slab.

FIGURE 1.—Locations of primary lead mines and deposits.



70%

FIGURE 2.—Locations of primary zinc mines and deposits.

Table 4.—Demonstrated resources for primary lead mines and deposits

State and property	Production Status	Production Years[1]	Resources, 10^3 t	Lead Grade, pct	Lead Contained, 10^3 t	Zinc Grade, pct	Zinc Contained, 10^3 t
Colorado: Bulldog	P	W	W	W	W	W	W
Idaho: Luck Friday	P	W	W	W	W	W	W
Missouri:							
Boss-Bixby	N	W	W	W	W	W	W
Brushy Creek Division	P	44	48,121	5.97	2,873	1.14	549
Buick Mine	P	25	45,336	7.00	3,174	1.90	861
Fletcher	P	38	40,722	8.67	3,531	.61	248
Higdon-Bonne Terre	N	14	2,551	8.05	205	2.20	56
Indian Creek	P	5	2,717	2.55	69	NA	NA
Magmont Mine	P	38	34,703	6.33	2,197	1.15	399
Milliken Mine	P	21	41,162	5.75	2,367	2.30	947
Viburnum No. 28 and No. 29	P	34	56,900	5.81	3,306	.47	267
Viburnum No. 35	N	W	W	W	W	W	W
West Fork	N	32	13,605	7.31	995	.87	118
Utah: Ontario	P	7	1,554	8.52	132	5.45	85
Total or weighted average	NAp	NAp	315,262	6.46	20,363	1.20	3,752

N Nonproducing property as of January 1, 1982. NA Not available. NAp Not applicable. P Producing property as of January 1, 1982.
W Withheld, company proprietary data. [1] Estimated number of production years remaining as of January 1, 1982.

Table 5.—Summary of demonstrated resources values for domestic lead

Status	Number of properties	Resources 10^3 t	Resources pct	Grade,[1] pct	Contained lead 10^3 t	Contained lead pct	Recoverable lead 10^3 t	Recoverable lead pct
Primary lead:								
Producer	9	274,967	87	6.58	18,086	89	15,592	89
Nonproducer	5	40,295	13	5.65	2,277	11	1,928	11
Total	14	315,262	100	6.46	20,363	100	17,520	100
Byproduct lead:								
Producer	5	11,439	3	1.74	199	3	139	3
Nonproducer	16	379,860	97	1.76	6,692	97	5,439	97
Total	21	391,299	100	1.76	6,891	100	5,578	100
Grand total	35	706,561	NAp	3.86	27,254	NAp	23,098	NAp

NAp Not applicable. [1] Weighted average.

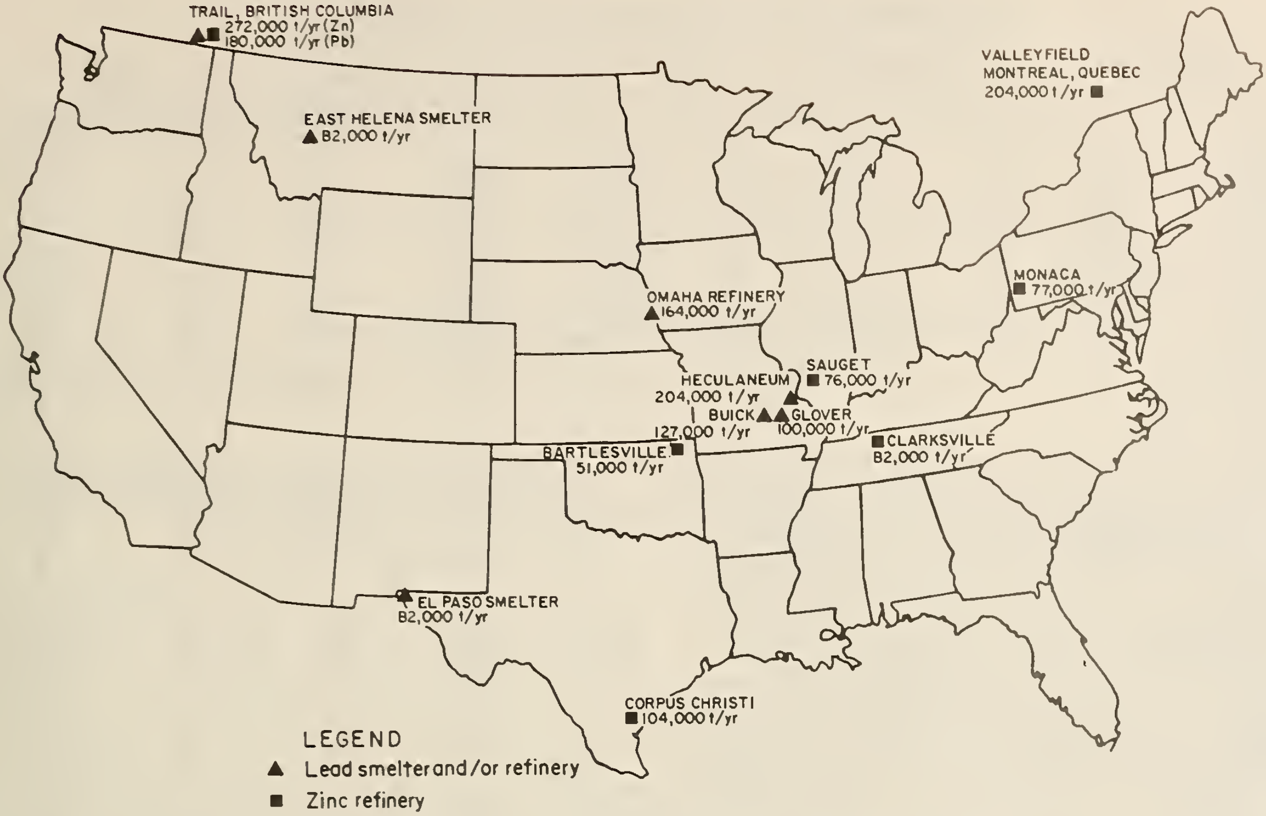


FIGURE 3.—Locations of smelter and refinery facilities utilized.

Mine production levels from 1977 to 1981 averaged 518,000 t of primary lead per year (*2*). The majority of the primary lead resources included in this evaluation are available from currently producing operations, with adequate resources to maintain fairly constant production levels (between 500,000 and 600,000 t of primary lead per year) over the next 20 yr.

The 1982 refinery capacity was 595,000 t of lead bullion per year from four refineries, not including the Bunker Hill facility. Lead refinery capacity is adequate to cover present production needs; however, the annual probable U.S. demand for primary lead in the year 2000 has been forecasted at 800,000 t/yr (*18*). Assuming that the domestic refining capacity is maintained and not replaced by imported refined products, the annual domestic primary lead refinery capacity would need to be increased by approximately 205,000 t in order to attain the projected annual domestic refinery capacity of 800,000 t of primary refined lead by the year 2000.

The peak annual production level for the primary lead operations evaluated would only be 581,000 t of primary refined lead per year, and the current smelter-refinery capacity of 595,000 t would be sufficient. Although the smelter-refinery capacity would need to be increased by the year 2000 to meet the projected volume of 800,000 t of primary refined lead per year, the resources included in this evaluation could adequately meet the demand if domestic annual production levels were increased. The peak rate for this evaluation, 581,000 t, was arrived at by assuming that current domestic production levels remain constant and that all preproduction development work began January 1, 1982. The cumulative demand through the year 2000 is forecast at 13.3 million t of recovered lead (*18*). The 14 operations included in this evaluation could provide approximately 17.5 million t of recoverable lead over their collective production lives; however, not all of this tonnage is contained in currently economical resources.

PRIMARY ZINC RESOURCES

Demonstrated resources for the 53 mines and deposits evaluated as primary zinc operations for this study total 1.04 billion t with a weighted average in situ grade of 4.73 pct zinc. These in situ resources contain 49.2 million t of zinc and approximately 6.9 million t of byproduct lead. See table 6 for a property listing of the resource tonnages and in situ grades for the primary zinc operations.

The 53 primary zinc mines and deposits evaluated for this study contain 49.2 million t of zinc, and an additional 3.8 million t of zinc is contained as a byproduct in mines and deposits that have been classified as primary lead operations. This results in a U.S. total of nearly 53 million t of contained zinc from 65 of the 67 mines and deposits evaluated. Only two of the deposits evaluated for this study did not recover zinc.

As illustrated in table 7, only 15 pct (162.6 million t) of the in situ primary zinc resources containing 6.2 million t of zinc are available from the 16 currently producing mines. From these current producers, 4.2 million t of primary zinc and 139,000 t of byproduct lead could be recovered.

As of January 1, 1982, 37 of the 53 primary zinc operations included in this evaluation were either on standby status, closed indefinitely, or were in various stages of development. Of the 877 million t of demonstrated primary zinc resources potentially available from these 37 operations, 146 million t is potentially available from two large deposits, the Red Dog in Alaska and the Crandon deposit in Wisconsin.

The Red Dog deposit is currently the largest primary zinc deposit in the United States with reported demonstrated resources of 77.1 million t and an in situ zinc grade of 17.1 pct (*19*). The high zinc grades for these two deposits increase the weighted average grade for all primary zinc mines and deposits included in this study by 1.14 pct, from 3.59 to 4.73 pct. As illustrated in table 8 the Red dog deposit alone has

Table 6.—Demonstrated resources for primary zinc mines and deposits

State and property	Production		Resources, 10^3 t	Zinc		Lead	
	Status	Years[1]		Grade, pct	Contained, 10^3 t	Grade, pct	Contained, 10^3 t
Alaska:							
Arctic	N	10	30,838	5.50	1,696	1.00	308
Greens Creek	N	16	3,810	10.04	383	3.29	125
Lik	N	W	W	W	W	W	W
Red Dog	N	71	77,095	17.10	13,183	5.00	3,855
Colorado:							
Black Cloud (Leadville Unit)	P	6	1,337	10.08	135	4.97	66
Idarado	N	9	3,754	3.89	146	2.72	102
Sunnyside	P	6	1,542	3.40	52	2.10	32
Idaho:							
Bunker Hill	N	W	W	W	W	W	W
Star-Morning	P	W	W	W	W	W	W
Illinois: Minerva No. 1-Spivey	P	W	W	W	W	W	W
Kentucky:							
Burkesville Project	N	W	W	W	W	W	W
Fountain Run	N	W	W	W	W	W	W
Maine:							
Bald Mountain	N	19	32,659	2.00	653	1.50	490
Kerramerican-Blue Hill	N	W	W	W	W	W	W
Montana: Butte District Zinc	N	W	W	W	W	W	W
Nevada:							
Ruby Hill	N	W	W	W	W	W	W
Ward Mountain	N	W	W	W	W	W	W
New Jersey: Sterling	P	8	1,362	18.90	257	NA	NA
New Mexico: Pinos Altos	N	10	7,000	3.00	210	NA	NA
New York:							
Balmat	P	6	6,218	8.50	529	.45	28
Pierrepont	P[2]	17	2,358	20.13	475	NA	NA
Pennsylvania: Friedensville Mine	P	W	W	W	W	W	W
Tennessee:							
Beaver Creek	P	7	3,805	3.90	148	NA	NA
Big War Creek	N	8	2,136	4.40	94	NA	NA
Carthage Property	N	W	W	W	W	W	W
Copperhill	P	40	39,656	1.26	502	NA	NA
Coy	N	15	3,550	3.96	141	NA	NA
Cub Creek	N	W	W	W	W	W	W
Cumberland	N	W	W	W	W	W	W
Cumberland Deposit	N	W	W	W	W	W	W
Cumberland Property	N	W	W	W	W	W	W
East Gainesboro	N	W	W	W	W	W	W
Gainesboro	N	W	W	W	W	W	W
Gordonsville-Elmwood	P	16	26,984	4.60	1,241	NA	NA
Hartsville	N	W	W	W	W	W	W
Hartsville Area	N	W	W	W	W	W	W
Idol	P	8	2,073	4.40	91	NA	NA
Immel	N	55	31,700	3.08	976	NA	NA
Jefferson City Mine	P	19	926	4.30	40	NA	NA
Lost Creek	P	15	1,849	3.60	67	NA	NA
New Market	P	71	50,651	2.80	1,418	NA	NA
Pall Mall	N	W	W	W	W	W	W
Right Fork	N	W	W	W	W	W	W
Roaring River	N	W	W	W	W	W	W
Stonewall	N	18	6,930	4.37	303	NA	NA
Young	N	32	27,100	3.25	881	NA	NA
Zinc Mine	P	W	W	W	W	W	W
Washington:							
Boundary Dam-Metaline Falls	N	W	W	W	W	W	W
Washington Zinc Unit	N	W	W	W	W	W	W
Wisconsin:							
Crandon	N	23	65,800	5.80	3,816	.50	329
Crawhall-Elmo No. 3	N	5	1,276	3.70	47	.10	1
Pelican River	N	4	1,450	8.00	116	NA	NA
Shullsburg-Bearhole	N	5	2,441	3.00	73	.15	4
Total or weighted average	NAp	NAp	1,039,630	4.73	49,197	1.76	6,891

N Nonproducing property as of January 1, 1982. NA Not available. NAp Not applicable.
P Producing property as of January 1, 1982. W Withheld, company proprietary data.
[1] Estimated number of production years remaining as of January 1, 1982.
[2] Began production April 1982.

27 pct of the total contained primary zinc. It also makes a major contribution to the amount of byproducts recoverable with 65 pct of the total byproduct lead and 42 pct of the total byproduct silver potentially recoverable from all primary zinc operations evaluated for this study.

Although the Crandon deposit has 65.8 million t of resources and a higher than average zinc grade, 5.8 pct versus 4.73 pct for the United States, it does not contribute the large amounts of primary zinc and byproduct lead that the Red Dog deposit does. The Crandon deposit could poten-

Table 7.—Summary of demonstrated resources values for domestic zinc

Status	Number of properties	Resources		Grade,[1] pct	Contained zinc		Recoverable zinc	
		10^3 t	pct		10^3 t	pct	10^3 t	pct
Primary zinc:								
Producer	16	162,622	16	3.80	6,178	13	4,151	10
Nonproducer	37	877,008	84	4.91	43,019	87	35,730	90
Total	53	1,039,630	100	4.73	49,197	100	39,881	100
Byproduct zinc:								
Producer	7	271,515	87	1.23	3,330	93	2,130	90
Nonproducer	5	40,295	13	1.05	422	7	246	10
Total	12	311,810	100	1.20	3,752	100	2,376	100
Grand total	65	1,351,440	NAp	3.92	52,949	NAp	42,257	NAp

NAp Not applicable. [1] Weighted average.

Table 8.—Comparison of Crandon and Red Dog deposits' resource values with total primary zinc resource values

	Operations[1] Crandon	Red Dog	Others	Total resources
Demonstrated resources:				
Tonnage .... 10^3 t..	65,800	77,095	896,735	1,039,630
Percent of total	6	7	86	100
In situ zinc grade .... pct..	5.8	17.1	[2]3.59	[2]4.73
Contained zinc:				
Tonnage .... 10^3 t..	3,816	13,183	32,198	49,197
Percent of total	8	27	65	100
Recoverable zinc:				
Tonnage .... 10^3 t..	3,108	11,628	25,146	39,881
Percent of total	8	29	63	100

[1] Total of 53. [2] Weighted average in situ grade zinc.
NOTE.—Data may not add to totals shown because of independent rounding.

tially recover 8 pct (3.1 million t) of the total recoverable zinc and 4 pct of the byproduct lead evaluated for this study. Like the Red Dog deposit, Crandon also makes a major contribution to the total amount of byproducts recoverable from all of the primary zinc operations evaluated, with 10 pct of the total byproduct silver, 29 pct of the total byproduct copper, and 47 pct of the total byproduct gold.

In summary, a total of 4.2 million t of recoverable primary zinc is potentially available from the 16 producing operations, and a total of 35.7 million t of recoverable zinc is potentially available from the 37 operations not currently in production. An additional 5.4 million t of byproduct lead could also be recovered from the nonproducing operations, which is 97 pct of the total potentially recoverable byproduct lead. Including the 2.4 million t of byproduct zinc available from the primary lead resources, total zinc potentially recoverable from the mine and deposits evaluated for this study was estimated at 42.3 million t.

DOMESTIC ZINC CAPACITY

Zinc concentrates are processed domestically by electrothermic and roast-leach-electrolytic methods that produce slab (primary refined) zinc, and as of January 1, 1982, there were five primary slab zinc processing facilities operating in the United States. With a slight increase in capacity at the Monaca, PA, facility, the 1982 postmill processing capacity was 390,000 t of refined zinc per year, down from 484,000 t of capacity in 1981, with the closure of Bunker Hill. This low capacity level would be insufficient if a large number of the currently inactive mines or undeveloped deposits were to come on line together in the future. Increased production levels, and even additional postmill processing capacity, would be required to meet increased concentrate production rates. The maximum annual smelter production level established for the operations included in this evaluation was approximately 1.1 million t of slab zinc per year. However, this production level was arrived at by assuming that current production levels for the 16 producing operations would remain constant, and that all preproduction development work for the 37 nonproducing mines and deposits began January 1, 1982.

Total probable demand for slab (primary refined) zinc for the year 2000 has been forecast at 1,.05 million t (*20*). Annual domestic mine production requirements have been projected at 640,500 t of zinc recovered. Because the current domestic primary smelter capacity of 390,000 t (excluding Bunker Hill) would be inadequate to process this increased production level, additional postmill processing capacity would be required. If the United States was to process a greater percentage of its own resources and decrease its dependency on foreign sources of zinc in the future, the domestic mine production levels required would exceed the projected 640,500 t of slab zinc per year. However, there is a chance that continued low utilization levels may result in the closure of some additional facilities, thereby further decreasing the current domestic postmill processing capacity rather than increasing it.

Total cumulative recoverable zinc through the year 2000 has been forecast at 23 million t (*20*). Potentially, 39.9 million t of zinc could be recovered from the 53 primary zinc operations over their collective production lives. It should be stressed that 90 pct of the potentially recoverable zinc would come from undeveloped deposits or mines that are not currently producing owing to high operating costs and depressed metal prices.

SUMMARY OF DOMESTIC RESOURCES

In summary, without regard to economics, the lead and zinc resources available from the 67 mines and deposits included in this evaluation could provide adequate sources of metal over the next 20 yr, but postmill processing capacities would need to be increased in order to maintain the current level of self-sufficiency for lead, or possibly decrease the U.S. dependence on foreign sources of zinc. Greater utilization of foreign facilities in Canada, Japan, and Europe could lessen the burden of building additional facilities to process excess domestic mine production, however, utilization of the foreign facilities would not be of much help towards a goal of postmill processing self-sufficiency.

An option available to several of the larger zinc operations, such as the Crandon in Wisconsin, or several of the larger Tennessee operations, could be to build their own postmill processing facilities. Although the economic feasibility of additional facilities was not evaluated, new facilities would help to insure adequate processing capabilities, reduce transportation distances and associated costs, and above all, would reduce the dependency on foreign sources for zinc.

GENERAL GEOLOGY

Lead and zinc occur together largely because of similarities in their chemical behavior (*21*). This relationship is well illustrated in the sites evaluated. Five of the mines evaluated appear in the list of the top 15 producers for both lead and zinc (*1–2*). Twelve of the fourteen properties evaluated as primary lead properties for this study also contain recoverable zinc, and 20 of the 53 mines and deposits evaluated as primary zinc operations also contain recoverable lead. In addition, other minerals, particularly silver, copper, and gold, frequently occur with the lead and zinc minerals. The reader may refer to appendix C for a very general discussion on the geology of the deposits evaluated, which are listed on a State-by-State basis.

Most exploitable lead and zinc ores can be divided into five principal categories based on differences in their geologic occurrences: (a) volcanic-hosted submarine exhalative massive sulfide deposits, (b) sediment-hosted submarine exhalative deposits, (c) strata-bound carbonate-hosted deposits, (d) strata-bound sandstone-hosted deposits, and (e) vein, replacement, and contact metasomatic deposits (*22*). Of the 67 sites evaluated, 43 occur in Mississippi Valley-type (MVT) deposits, which are members of the strata-bound carbonate-hosted category (*22*). The other 24 mines and deposits occur in all of the remaining deposit types and will be referred to as non-Mississippi Valley-type (NMVT) deposits. Table 9 is a list of those deposits classified as NMVT deposits.

MVT deposits generally occur in marine carbonate rocks deposited in shallow water on stable craton areas, and mineralization is generally restricted to particular horizons within certain formations. The deposits are generally more extensive laterally than vertically, and open-space fillings are predominant.

The majority of all domestic lead and zinc resources are contained in MVT deposits, and 9 of the top 15 producers of both lead and zinc occur in MVT deposits. The 43 MVT deposits account for approximately 98 pct of the total in situ primary lead resources and 67 pct of the total in situ primary zinc resources.

The percentages are even higher for the producing mines evaluated. Approximately 98 pct of the primary lead resources and approximately 81 pct of the primary zinc resources in producing mines are located in MVT deposits. Resources from undeveloped MVT deposits or nonproducing mines account for approximately 99 pct of the remaining primary lead resources and 64 pct of the remaining primary zinc resources (1 pct and 26 pct are nonproducing NMVT deposits for lead and zinc, respectively). While the ratio of MVT to NMVT deposit types will probably remain consistent for the future production of lead, a higher percentage of zinc could become available from NMVT deposits. Consequently, NMVT deposits will probably be the source of a higher percentage of zinc production in the future.

Table 9.—Non-Mississippi Valley-type deposits

State and property	*Primary commodity*
Alaska:	
Lik	Zinc.
Arctic	Do.
Greens Creek	Do.
Red Dog	Do.
Colorado:	
Black Cloud	Do.
Bulldog	Lead.
Idarado	Zinc.
Sunnyside	Do.
Idaho:	
Bunker Hill	Do.
Lucky Friday	Lead.
Star-Morning	Zinc.
Maine:	
Bald Mountain	Do.
Kerramerican-Blue Hill	Do.
Montana: Butte District Zinc	Do.
Nevada:	
Ruby Hill	Do.
Ward Mountain	Do.
New Jersey: Sterling	Do.
New Mexico: Pinos Altos	Do.
New York:	
Balmat	Do.
Pierrepont	Do.
Tennessee: Copperhill	Do.
Utah: Ontario	Lead.
Wisconsin:	
Crandon	Zinc.
Pelican River	Do.

The NMVT deposits evaluated contain a higher value of recoverable byproducts than do the MVT deposits. Higher byproduct revenues generated from NMVT deposits will offset a portion of the production costs and could make the NMVT deposits more attractive for development. This subject is dealt with more completely in the following section on deposit type and the relationship to byproduct content.

A difference in mining methods and costs also exists between MVT and NMVT deposits. The majority of the MVT deposits are mined using some form of room-and-pillar mining, with operating costs that are generally lower than those methods used to mine the NMVT deposits. This subject is dealt with more thoroughly in the "Mining Methods and Costs" section.

DEPOSIT TYPE AND RELATIONSHIP TO BYPRODUCT CONTENT

Some of the factors that determine the type of mineralogy occurring in any deposit are temperature, pressure, and depth of mineral deposition; chemistry of the host rock; and chemistry of the ore-bearing fluids. These and other factors contribute to the uniqueness of any deposit and determine the type of mineral assemblage that results. Differences in mineral assemblage strongly influence the economics of the lead and zinc operations evaluated. This is reflected in the fact that production of byproduct gold, silver, and copper varies widely between MVT and NMVT deposits.

Tables 10 and 11 show what commodities were recovered as byproducts, in addition to the primary commodity, during the evaluation of each site. In a few instances, mines in this study may recover other byproducts in addition to those listed. If data about additional byproducts were insufficient, recovery sporadic, or the mine did not receive payment for that byproduct from the smelter, then the commodity was not included in the evaluation. Therefore, while the trends discussed in this evaluation are representative of the domestic operations included, it should be kept in mind that they are not absolute.

Revenues generated by byproduct gold, silver, and copper may be substantial, and in some cases may be the determining factor as to whether a particular deposit is exploited, or whether a particular mine remains open. However, not all deposits, regardless of MVT or NMVT classification, contain gold, silver, or copper. Of those that do contain these byproducts, significant differences exist.

Table 10.—Commodities recovered as byproducts at primary lead properties

State and property	Deposit type	Commodities
Colorado: Bulldog	NMVT	Silver.
Idaho: Lucky Friday	NMVT	Zinc, silver, gold.
Missouri:		
Boss-Bixby	MVT	Zinc, copper.
Brushy Creek Division	MVT	Zinc, copper, silver, cadmium.
Buick	MVT	Do.
Fletcher	MVT	Do.
Higdon-Bonne Terre	MVT	Zinc, copper.
Indian Creek	MVT	Copper, silver
Magmont	MVT	Zinc, copper, silver, cadmium.
Milliken	MVT	Zinc, silver, cadmium.
Virburnum No. 28 and No. 29	MVT	Zinc, copper, silver, cadmium.
Virburnum No. 35	MVT	Zinc, copper.
West Fork	MVT	Zinc, copper, silver, cadmium.
Utah: Ontario	NMVT	Zinc, silver.

MVT Mississippi Valley type. NMVT Non-Mississippi Valley type.

Gold is not presently recovered from operations located in MVT deposits; gold is credited for 1.2 to 77.5 pct[6] of the revenues at NMVT operations where it is recovered. These percentages of revenues are based on the January 1982 prices of $384.12 per troy ounce of gold, $0.30 per pound of lead, and $0.42 per pound of zinc.

Most of the MVT deposits included in this study do not contain recoverable amounts of silver. Silver is recovered only from eight of the MVT deposits located in the Southeast Missouri District. However, owing to their size, these eight operations are responsible for 19 pct of the total silver recovered from all lead and zinc operations included in the evaluation. Using prices of $8.03 per troy ounce of silver, and $0.30 per pound of lead, silver is credited for only 0.1 to 4.5 pct of the revenues generated at the MVT deposits located in the Southeast Missouri District. In the NMVT deposits where silver is recovered, it accounts for 28.3 to 93.4 pct of the revenues generated at mines and deposits evaluated as primary lead operations, and using a price of $0.42 per pound of zinc, silver accounts for 0.4 to 38.2 pct of the revenues generated for mines and deposits evaluated as primary zinc operations.

Copper is recovered from 10 of the MVT deposits. All of these are located in the Southeast Missouri District, and are anomalously enriched in copper relative to most other MVT deposits. The 10 Missouri operations are responsible for 16 pct of the total copper recovered from lead and zinc operations included in this evaluation. Using prices of $0.79 per pound of copper and $0.30 per pound of lead, copper is credited for up to 26.2 pct of the revenues generated at the operations located in the Southeast Missouri District. Copper recovered from primary zinc operations located in NMVT deposits accounts for 6.2 to 61.9 pct of the revenues at a $0.42-per-pound price for zinc.

Although table 9 shows that the deposits in the Southeast Missouri District are considered to be MVT deposits, they are atypical, and their classification as such is currently being reviewed. Their lead-zinc-silver-copper (and sometimes cobalt and nickel) ores are extremely unusual when compared with ores of other MVT deposits. In addition, small amounts of gold have also been produced from the some of the Missouri deposits in the past, and it is probable that at some time in the future significant, though small amounts, of gold will be recovered from copper-cobalt-nickel ore bodies not yet exploited (*21*). Most MVT deposits do not contain recoverable amounts of silver, copper, nickel, cobalt, or gold. If the southeast Missouri deposits were to be reclassified as NMVT deposits at some point in the future, there would be no silver, copper, or gold recovered from any of the domestic MVT deposits evaluated. This would make the previous points on deposit type and byproduct content even stronger.

In summary, the NMVT deposits evaluated generally contain a higher value of recoverable byproducts than do the MVT deposits. Revenues generated from byproducts as a percentage of total revenues generated from NMVT deposits may range as high as 93 pct for silver, 78 pct for gold, and 62 pct for copper using the January 1982 market prices for these commodities. MVT deposits do not have the high quantity of byproducts that NMVT deposits do, and the percentage of total revenues generated from byproducts is much lower; only up to 4.5 pct for silver and 26 pct for copper. There is no gold presently recovered from MVT deposits. The high byproduct revenues generated from NMVT deposits can offset a portion of the production costs and make the NMVT deposits more attractive to development. Therefore, NMVT deposits are likely to be the source of a higher percentage of zinc production in the future.

The effects of fluctuating metal prices on the economic availability of lead and zinc resources potentially recoverable from the mines and deposits evaluated are discussed later in the "Sensitivity Analyses" section. The difference in mining methods and costs that exists between MVT and NMVT deposits is discussed in the following section.

Table 11.—Commodities recovered as byproducts at primary zinc properties

State and property	Deposit type	Commodities
Alaska:		
Arctic	NMVT	Lead, copper, silver.
Greens Creek	NMVT	Lead, silver, gold.
Lik	NMVT	Lead, silver.
Red Dog	NMVT	Do.
Colorado:		
Black Cloud	NMVT	Lead, silver, gold.
Idarado	NMVT	Lead, copper, silver, gold.
Sunnyside	NMVT	Do.
Idaho:		
Bunker Hill	NMVT	Lead, silver.
Star-Morning	NMVT	Do.
Illinois: Minerva No. 1-Spivey	MVT	Lead, fluorspar, barite.
Kentucky: Burkesville Project	MVT	Lead.
Maine:		
Bald Mountain	NMVT	Copper.
Kerramerican-Blue Hill	NMVT	Do.
Montana: Butte District Zone	NMVT	Lead, copper, silver.
Nevada:		
Ruby Hill	NMVT	Lead, silver, gold.
Ward Mountain	NMVT	Lead, copper, silver.
New Mexico: Pinos Altos	NMVT	Copper.
New York: Balmat	NMVT	Lead, silver.
Pennsylvania: Friedensville Mine	MVT	Limestone.
Tennessee:		
Copperhill	NMVT	Copper, iron.
Cumberland Deposit	MVT	Cadmium.
Cumberland Property	MVT	Do.
Gordonsville-Elmwood	MVT	Limestone.
Jefferson City Mine	MVT	Do.
Right Fork	MVT	Cadmium.
Washington:		
Boundary Dam-Metaline Falls	MVT	Lead.
Washington Zinc Unit	MVT	Do.
Wisconsin:		
Crandon	NMVT	Lead, copper, silver, gold.
Crawhall-Elmo No. 3	MVT	Lead.
Pelican River	NMVT	Copper.
Shullsburg-Bearhole	MVT	Lead.

MVT Mississippi Valley type. NMVT Non-Mississippi Valley type.

[6]Operations receiving a large percentage of their revenues from commodities that were considered byproducts for this evaluation may actually be recovering the lead and/or zinc as coproducts. These operations are included herein as primary lead or zinc operations because they recover significant quantities of lead and/or zinc.

MINING METHODS AND COSTS

There is a definite correlation between the geology of a particular deposit and the type of mining method used. All of the MVT deposits evaluated are geologically similar and the methods used to mine them are also similar. Figure 4 illustrates this relationship between the deposit type and the mining method. Ninety-eight percent of the resource tonnages classified as MVT deposits are mined by room-and-pillar, or room-and-pillar in combination with some other mining method. Conversely, only 4 pct of the resource tonnages classified as NMVT deposits are mined solely by room-and-pillar methods.

Tables 12 and 13 show the mining methods used or proposed in the lead and zinc sites evaluated. All primary lead operations, and all but five of the primary zinc operations evaluated, either utilize or plan to utilize underground mining methods. The remaining five sites, all NMVT primary zinc deposits, used or planned to use open pit methods. Most of the deposits are mined by room-and-pillar, sublevel stoping, shrinkage stoping, or cut-and-fill methods. Room-and-pillar mining was utilized most frequently, either alone or in combination with sublevel stoping or shrinkage stoping methods. The latter methods are used in portions of an ore body that are not amenable to room-and-pillar mining owing to its shape, attitude, or structural features. Historically, sublevel stoping and shrinkage stoping have both been used in combination with room-and-pillar methods in the Tennessee-Kentucky mines where breakthrough ore bodies were encountered during the course of mining.

Drilling at all of the underground operations is usually done by jumbo drills, but jackleg drills and vertical long-hole air-track drills are sometimes used when conditions warrant them. Where distances are short, hauling is usually done by load-haul-dumpers (LHD's), but longer hauls may be done with trucks, converyors, or rail equipment. Many of the mines have underground crushers that crush the ore before it is hoisted. Most of the mines are accessed by shafts, but inclines and, to a lesser extent, adits may also be used.

Table 12.—Mining methods used or proposed for primary lead operations

State and property	Mining methods
Colorado: Bulldog	Undercut and fill.
Idaho: Lucky Friday	Cut and fill.
Missouri:	
Boss-Bixby	Room-and-pillar.
Brushy Creek Division	Do.
Buick	Do.
Fletcher	Do.
Higdon-Bonne Terre	Do.
Indian Creek	Do.
Magmont	Do.
Milliken Mine	Do.
Virburnum No. 28 and No. 29	Do.
Virburnum No. 35	Do.
West Fork	Do.
Utah: Ontario	Cut and fill.

ROOM-AND-PILLAR METHODS

Room-and-pillar mining is used where ore bodies are comparatively flat lying or where the ore occurs in large bodies. In room-and-pillar mining, chambers are excavated and pillars are left standing to provide support for the overlying rock. The pillars may be recovered during the last stages of mining, if they are of sufficient grade to make recovery economical.

Approximately 98 pct of the primary lead resource tonnage and 8 pct of the primary zinc resource tonnage are mined by room-and-pillar methods only. Figure 5 shows a breakdown of mining methods by primary commodity. Nineteen of the twenty-one mines that use room-and-pillar methods solely are MVT deposits. All of the mines and deposits in the Southeast Missouri District and the Copper

Table 13.—Mining methods used or proposed for primary zinc operations

State and property	Mining methods
Alaska:	
Arctic	Open pit.
Greens Creek	Underhand cut and fill.
Lik	Open pit.
Red Dog	Do.
Colorado:	
Black Cloud	Room-and-pillar with fill.
Idarado	Shrinkage stoping.
Sunnyside	Do.
Idaho:	
Bunker Hill	Room-and-pillar, cut and fill.
Star-Morning	Cut and fill.
Illinois: Minerva No. 1-Spivey[1]	Room-and-pillar, shrinkage stoping.
Kentucky:	
Burkesville Project	Do.
Fountain Run	Do.
Maine:	
Bald Mountain	Open pit.
Kerramerican-Blue Hill	Room and pillar.
Montana: Butte District Zinc	Cut and fill, sublevel cave, block caving with minor underhand stoping.
Nevada:	
Ruby Hill	Cut and fill, open stope.
Ward Mountain	Room-and-pillar.
New Jersey: Sterling	Cut and fill, limited square set.
New Mexico: Pinos Altos	Open stope.
New York:	
Balmat	Room-and-pillar, sublevel stoping, contour mining, sublevel benching, uphill slab and lifter stoping.
Pierrepont	Do.
Pennsylvania: Friedensville Mine	Room-and-pillar, open stope.
Tennessee:	
Beaver Creek	Room-and-pillar.
Big War Creek	Do.
Carthage Property	Room-and-pillar, sublevel stoping.
Copperhill	Sublevel stoping, pillar, open pit.
Coy	Room-and-pillar, shrinkage stoping.
Cub Creek	Room-and-pillar, sublevel stoping.
Cumberland	Do.
Cumberland Deposit	Do.
Cumberland Property	Do.
East Gainesboro	Do.
Gainesboro	Do.
Gordonsville-Elmwood	Do.
Hartsville	Do.
Hartsville Area	Do.
Idol	Room-and-pillar.
Immel	Room-and-pillar, shrinkage stoping.
Jefferson City Mine	Do.
Lost Creek	Do.
New Market	Do.
Pall Mall	Room-and-pillar, sublevel stoping.
Stonewall	Do.
Right Fork	Do.
Roaring River	Do.
Young	Room-and-pillar, shrinkage stoping.
Zinc Mine	Room-and-pillar.
Washington:	
Boundary Dam-Metaline Falls	Room-and-pillar.
Washington Zinc Unit	Blasthole stoping.
Wisconsin:	
Crandon	Sublevel blasthole, open stope with fill.
Crawhall-Elmo No. 3	Room-and-pillar.
Pelican River	Cut and fill.
Shullsburg-Bearhole	Room-and-pillar.

[1] Minerva No. 1 is mined by room-and-pillar and Spivey is mined by shrinkage stoping. They were combined for evaluation purposes because they use a common mill.

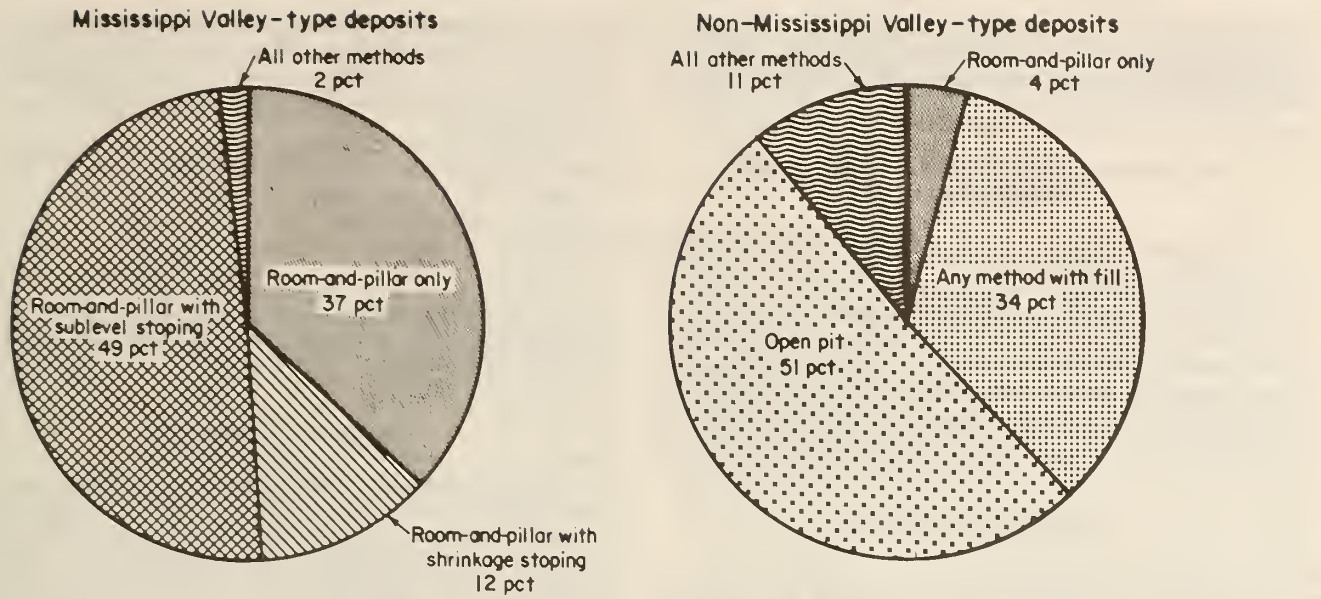


FIGURE 4.—Relationship between mining methods and deposit classification.

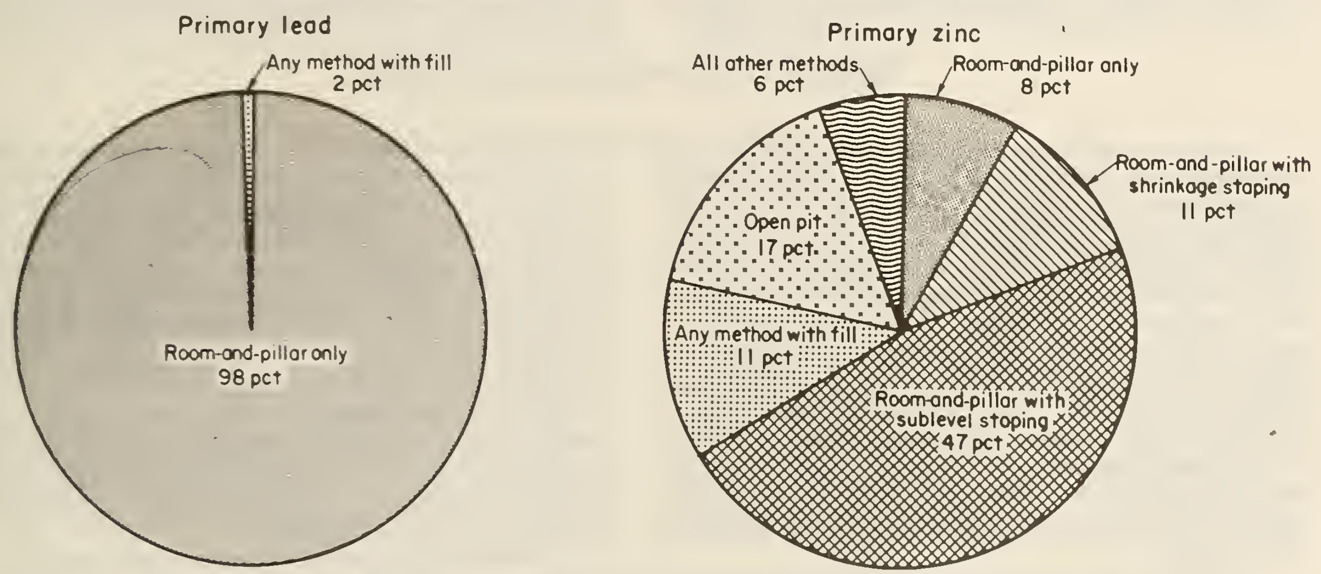


FIGURE 5.—Breakdown of mining methods by primary commodity.

Ridge District in Tennessee were evaluated using room-and-pillar mining only. Mine operating costs for room-and-pillar mining range from $8 to $26 per metric ton, with costs at most of the mines in the lower third of this range.

Table 14 provides a breakdown of mine operating costs by mining method, MVT deposit status, and primary commodity. The mine operating costs are shown as ranges to protect confidential company data. These ranges are quite wide, which illustrates the high degree of variability between individual operations.

Table 14.—Selected mine operating costs[1]

Mining method	Deposit type	Cost per metric ton	Primary commodity
Room-and-pillar only	MVT, NMVT	$8–$26	Lead, zinc.
Room-and-pillar with sublevel stoping	MVT	8– 11	Zinc.
Room-and-pillar with shrinkage stoping	MVT	11– 20	Do.
All backfill methods	NMVT	21– 76	Lead, zinc.
Open pit	NMVT	3– 24	Zinc.

MVT Mississippi Valley type NMVT Non-Mississippi Valley type.
[1] Costs in January 1982 dollars

ROOM-AND-PILLAR WITH SUBLEVEL STOPING METHODS

A combination of room-and-pillar and sublevel stoping methods is used at the mines in the MVT deposits in the Central Tennessee-Kentucky region. In sublevel stoping, sublevels are driven above the main levels at intervals up to the hanging wall. The ore is blasted and drawn through ore passes to the main haulage levels. Mining is started on the uppermost sublevels first, retreating down to the main levels. Pillars may or may not be left. This method is only used where both the walls and the ore are strong.

Central Tennessee-Kentucky sites account for all of the 16 deposits utilizing combined room-and-pillar and sublevel

stoping. Approximately 47 pct of the primary zinc resources are mined by these combined methods. Mine operating costs at the Central Tennessee-Kentucky sites range from $8 to $11 per metric ton.

ROOM-AND-PILLAR WITH SHRINKAGE STOPING METHODS

Shrinkage stoping is used in combination with room-and-pillar mining in most of the MVT deposits of the Mascot-Jefferson City District. In shrinkage stoping, the stopes are developed by blasting upward through the back of the stope and then using the rubble as a working floor for the next cycle of blasting. The cycle continues until the hanging wall is reached, and at that time the stope is mucked out. Eleven percent of the primary zinc resources are mined using this room-and-pillar with shrinkage stoping combination. Mine operating costs range from $11 to $20 per metric ton.

BACKFILL METHODS

Two percent of the primary lead resources and 11 pct of the primary zinc resources are mined using backfill methods. Backfill methods are used where it is necessary to recover as much of the ore as possible and the country rock is not self-supporting. After the stopes are mined out, they are filled with sand (mill tailings) or a sand and cement mixture. Mining can then proceed immediately adjacent to the filled stope. Sand for the backfill is supplied by the milling operations.

All 12 deposits that use cut and fill, undercut and fill, or other methods with fill are in NMVT deposits. With the exception of the Sterling Mine, all of the mines have concentrations of precious metals. The additional expense required to use backfill methods is offset by the greater value of the ore. However, in the case of the Sterling Mine, its inexpensive milling procedures offset the high cost of mining. Mine operating costs for mines employing backfill methods range from $21 to $76 per metric ton, with costs fairly well distributed throughout the range.

OPEN PIT METHODS

All of the mines that were evaluated as using open pit methods are primary zinc properties, and all of them occur in NMVT deposits. The resources from the open pit mines account for approximately 17 pct of the domestic primary zinc resources evaluated. Rotary drills and blasting are used, and the ore is excavated by means of electric shovels and front-end loaders, with haulage to the mill by trucks. Operating costs for open pit mining range from $3 to $24 per metric ton.

MILLING METHODS AND COSTS

All of the sites except the Sterling Mine use generally the same type of milling procedures whether the ore contains primarily lead, zinc, or is a mixed sulfide ore. However, the specific methods used are dependent on the characteristics of the ore at each operation. The ore undergoes crushing, grinding, classification, and sometimes heavy media separation. The heavy media separation reduces the amount of waste that goes through the rest of the milling process. The ore is then treated by flotation to make concentrates that are thickened, filtered, sometimes dried, and then stored for shipment. Up to three different concentrates may be produced at one mill. Lead, zinc, and copper are generally produced as separate concentrates. A combination lead-copper product is bulk floated, and then the lead and copper concentrates are separated by differential flotations. The tails from the lead-copper circuit become the feed for the zinc circuit, with the zinc concentrate being the final product in the flotation process.

Precious metals may be contained in all three of the concentrates, but the highest concentrations occur in the lead and copper concentrates. Cadmium, on the other hand, is generally contained in the zinc concentrates. Sometimes a mill will sacrifice good recovery of the zinc concentrate to obtain maximum recovery of the more valuable lead-silver concentrate, as is done at the Lucky Friday Mine. High silver values are also present at the Bulldog Mine, where a carbon-in-pulp plant has been recovering silver since 1976. This plant is treating old tailings in addition to the slimes from the flotation plant. At the Sunnyside Mine, sponge gold is produced by amalgamation of a jig concentrate high in gold and lead values.

In addition to lead, zinc, or copper concentrates, other products may be produced at some of the milling operations. Fluorspar and sometimes barite concentrates are produced after lead and zinc flotation at the Minerva No. 1-Spivey mill. Depending on market requirements, various grades of the fluorspar can be produced. An iron concentrate is also produced at the Copperhill mill. Agricultural limestone or other sand products are recovered from tailings at three producing operations. It was assumed that no limestone would be recovered from any sites that were evaluated as non-producers at the time of this study.

Only one site evaluated during the study does not beneficiate the ore. Milling operations at the Sterling Mine in New Jersey consist of dry crushing and grinding only. No further concentration of crude ore is necessary because of its already high natural grade of 18.9 pct zinc. The ore is sent directly to the company smelter.

Automation at several of the newer large Missouri operations makes them some of the most efficient mills in the world. For the operations evaluated in this study, mill operating costs ranged from $2 to $13 per metric ton of ore, except at the Sterling Mine where the ore is not beneficiated. The costs are variable because the milling operation at each operation is unique and is designed specifically for its particular ore, even though the same general procedures are used. Some factors that contribute to the wide range of milling costs are chemical composition of the ore, hardness of the ore, final grinding size needed, age of the mill, efficiency of the mill, quantity and quality of final products desired, and size and location of the mill.

POSTMILL COSTS

Postmill costs are normally under little control of a mining company, except in the case where a mine-mill and smelter-refinery complex are owned by the same company. The costs of transportation and postmill processing both vary widely, and any particular mining operation will probably send its concentrates to the smelter that results in the most favorable terms to the mining company on a delivered and sold basis. Because detailed information pertaining to transportation and postmill processing was not available (or was confidential) for many of the operations, it was assumed for this study that most concentrates were shipped to the nearest facility, and that a common treatment schedule was

used by all of the facilities, regardless of the location, concentrate requirements, or the capacity available at any particular facility.

Domestic capacity was augmented by shipping lead and zinc concentrates in the Northwestern United States to the Cominco facility in Trail, British Columbia, and zinc concentrates from the Maine operations were shipped to the Valleyfield facility in Montreal, Quebec. All concentrates from Alaskan operations were transported by truck, barge, and/or rail to the nearest port and shipped to Japan for postmill processing. Refer to figure 3 for a map indicating the locations and capacities of the U.S. and Canadian postmill processing facilities utilized.

TRANSPORTATION

Truck, barge, and rail rates were applied using known rates, if available, or estimated rates, which were supplied by transportation companies, for the routes over which each concentrate would travel. The variability and uncertainty of transportation costs are best illustrated by the situation that exists in the railroad industry. Negotiated rates (rates that are a result of a contractual agreement between a shipper and the railroad) exist only on routes where lead and zinc concentrates are currently being shipped. Class rates (rates that apply to bulk freight) are applied to those routes that do not currently handle lead or zinc concentrates. Class rates are higher than negotiated rates, but there is no rule of thumb relationship to predict what the negotiated rate would be from any class rate. The negotiated rate decided on by the mine and the railroad depends upon how keenly the railroad wants the business, what the rail costs are over that particular portion of the track, and what kind of capital expenditures are necessary in order to enable the railroad to carry the concentrate *(23)*.

Occasionally, negotiated rates or the alternative methods of transportation were available to a more distant facility and were less expensive than class rates to the nearest facility. In those cases, the least expensive route and rate were applied. In Alaska, for example, concentrates derived from this investigation were shipped to Japan at an average cost of $0.05 per pound of refined product. This can be compared with an average cost of $0.68 per pound of refined product for transporting the concentrates via a proposed interior Alaskan rail line to Anchorage, AK, and then by barge and rail to Trail, British Columbia. Actual transportation costs, which may vary considerably from those used in this investigation, will depend on the transportation method(s) chosen, what rates can be negotiated, and the location of the smelter of choice.

POSTMILL PROCESSING CONTRACT TERMS

In actual practice, smelter terms are negotiated individually between mines and smelters. Terms vary considerably from mine to mine and smelter to smelter owing to a number of different factors. Each facility is constructed with a particular feed in mind, and not all concentrates are suitable feed for all facilities. The terms of any contract will reflect the processor's degree of interest in acquiring a particular concentrate. Owing to the recent shortage of zinc concentrates, some smelters have been competing for concentrates in order to have enough plant feed to remain open, with the financial terms of the contract being a secondary issue. An increased number of less suitable concentrates were also being accepted, and in these cases, the terms to the mines may be unusually favorable. Actual smelter contracts will vary owing to numerous factors such as changes in metal prices, changes in labor and power rates at the facilities, metallurgy of the concentrates, amount of the contained metal in the concentrates, and the moisture content of the concentrates.

All of the operations were evaluated using a common smelter schedule because detailed information on the expected metallurgy of concentrates at all operations was not available, it was unknown what facilities would accept any particular concentrate, and because it was unknown what terms would be negotiated between each mine and any particular smelter. Smelter schedules were obtained from some of the companies that process zinc, lead, and copper ores, and a generalized smelter schedule, as shown in table 15,

Table 15.—Smelter schedule developed for domestic lead and zinc and copper concentrates

Concentrate and recoverable contained metals	Deduction before payment calculation	Remaining metal content paid for,[1] pct	Less
Zinc concentrate:			
Zinc	None	85	$0.01/lb.
Cadmium	..do	60	$1.00/lb.
Gold	0.02 tr oz gold per dry ton conc	75	$2.50/tr oz.
Silver	3 tr oz silver per dry ton conc	70	0.
Lead	3 wt pct lead	50	0.
Treatment charge	NAp	NAp	$223.07/t conc.
Lead concentrate:			
Lead	1 wt pct lead	94	$0.05/lb.
Gold	0.02 tr oz gold per dry ton conc	95	$5.00/tr oz.
Silver	1 tr oz silver per dry ton conc	95	$0.20/tr oz.
Copper	1.5 wt pct copper	60	$0.40/lb.
Treatment charge	NAp	NAp	$156.79/t conc.
Copper concentrate:			
Copper	1 wt pct copper	97.5	$0.14/lb
Gold	0.02 tr oz gold per dry ton conc	95	$5.00/tr oz.
Silver	1 tr oz silver per dry ton conc	95	$0.25/tr oz.
Treatment charge	NAp	NAp	$99.91/t conc.

Conc Concentrate NAp Not applicable. [1] At January 1982 prices (table 1).

was compiled from these responses. It must be stressed that actual negotiated terms could vary widely from this schedule; however, it was compiled to represent average rates.

Table 16 demonstrates how this generalized smelter schedule is applied to a particular concentrate. It can readily be seen from the calculations in table 16 that mines receive only a portion of the gross value of the metal contained in the concentrates, in this case 64 pct. It is also apparent that if the concentrate contained no silver values, the percentage of metal value paid for by the smelter would only be 46 pct.

As illustrated in table 16, mines do not receive payment for all of the contained metal content in the concentrates. As stated in reference 24: "The actual revenue received by the mine can vary from as little as 45 pct to more than 95 pct of the gross value of metal contained in the concentrate. Smelter terms are, therefore, a significant factor in the estimation of potential revenues from any new mining venture." It should be noted that the operations with higher concentrations of precious metals, which are located in NMVT deposits, generally receive a higher percentage of the gross metal value back from the smelters-refineries.

For the purposes of this investigation, the smelter treatment charge is handled as an operating cost incurred by the mine, rather than a debit against metal value given at the smelter, as is the actual practice. Either way, the treatment charge is a cost that must be paid by the mine for processing the concentrates. The costs to the mines for postmill processing of all concentrates range from 10 to 85 pct of the average total operating costs (i.e., mine and mill operating costs, transportation, and smelter charges) at the properties evaluated. The majority of smelter costs ranged from 20 to 50 pct of the average total operating cost. However, this does not apply to operations that have a unique situation such as exceptionally high or low mining, milling, or transportation costs, or when the concentrate grade is unusually low.

Use of the generalized smelter schedule includes several assumptions: (1) none of the concentrates are tolled, a situation where, after processing *(24)*, "all or part of the metal contained in the concentrate is returned to and marketed by the mine," (2) all of the concentrates are assumed to be acceptable feed for any of the facilities, and (3) none of the concentrates contain deleterious material of sufficient quantity to incur a penalty.

Table 16.—Application of the generalized smelter schedule

(75 pct lead concentrate containing 40.5 tr oz per ton silver)

	Cost per metric ton
Paid for by smelter:[1]	
For lead	$383.38
For silver	+323.88
Total for metals	707.26
Less treatment charge	−156.79
Total	550.47
Contained metal value:[2]	
Lead	496.04
Silver	+358.48
Total	854.52

[1] Values from table 15, prices from table 1.
Lead = (75 − 1 wt pct)(0.94)($0.30 − $0.05/lb)(2,204.6 lb/t).
Silver = (40.5 − 1 tr oz/ton)(0.95)($8.03 − $0.20/tr oz)(1.1023 ton/t).
[2] Prices from table 1.
Lead = (75 wt pct)($0.30/lb)(2,204.6 lb/t).
Silver = (40.5 tr oz/ton)($8.03/tr oz)(1.1023 ton/t).

OPERATING COSTS

The total operating cost of a mining project is a combination of direct and indirect costs. Direct operating costs include operating and maintenance labor and supplies, supervision, payroll overhead, insurance, local taxation, and utilities. The indirect operating costs include technical and clerical labor, administrative costs, maintenance of facilities, and research.

According to this evaluation, long-run operating costs for the large, efficient mines in the Viburnum Trend are competitive at current market prices. However, the lead and zinc operations in other parts of the country generally have much higher operating costs owing to the depth and structure of the ore bodies. These other operations often must depend upon byproduct revenues from precious metals, particularly silver, to offset the high cost of production. Figure 6 is a bar graph depicting the relationship between operating costs (the negative portion) and byproduct revenues (the positive portion), with each bar representing an individual operation.

This bar graph shows that operations with higher byproduct revenues tend to have higher operating costs as well. Those operations with the highest byproduct revenues are able to offset all or a substantial portion of the operating costs, thus improving their competitive position relative to those operations that do not benefit from byproduct revenues. This byproduct revenue-operating cost relationship can be further characterized by the type of deposit. Eighteen of the twenty-four NMVT deposits are represented in the first 20 bars, which demonstrates why a nonproducing NMVT deposit may have a better chance at being developed in the future than a MVT deposit with similar, or even superior lead or zinc grades.

Table 17 shows a percentage breakdown of total operating costs into mining and milling operating cost, transportation cost from the mill to the smelter, and smelting-refining treatment charges experienced by each present and proposed operation. The table indicates that the major portions of the operating costs are incurred during the mining and postmill processing stages.

Of the 67 operations evaluated, 55 were found to have mining operating costs ranging between 30 and 60 pct of the total operating cost for that operation. Smelter treatment charges ranged between 20 and 50 pct of the total for 62 of the operations. Milling operating costs were less than 30 pct for 61 operations, and transportation costs accounted for less than 10 pct of the total operating costs for 52 of the deposits evaluated. For all but two of the deposits, transportation costs were 20 pct or less of the total operating cost.

It should be noted that the transportation costs were generally estimated from the mill to the nearest postmill processing facility and that a common smelter schedule was developed and applied to all facilities. The use of a common smelter schedule does not take into account the actual varia-

Table 17.—Breakdown of operating costs showing the number of operations in each percentage category[1]

Percent of total	Mining	Milling	Transportation	Smelter charges
0 to 10	0	7	52	0
10 to 20	3	32	13	2
20 to 30	6	22	1	16
30 to 40	26	6	1	22
40 to 50	20	0	0	24
50 to 60	9	0	0	2
Over 60	3	0	0	1
Total	67	67	67	67

[1] Percentages of the total operating costs determined for each individual operation. The table is made up of data for both lead and zinc properties, as no difference was discernable between the two.

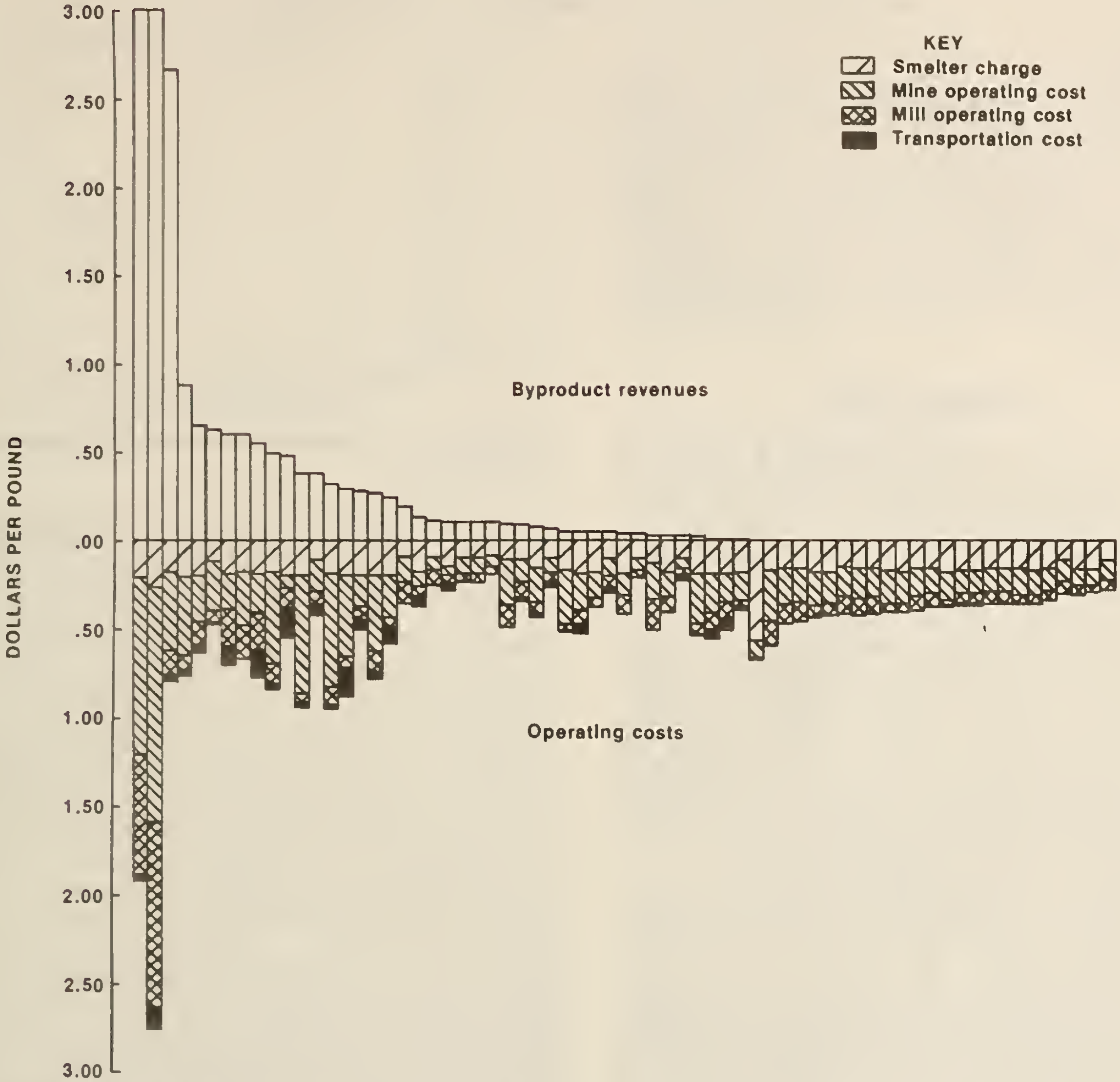


FIGURE 6.—Byproduct revenues and operating costs per pound of primary lead or zinc recovered at each operation.

tions in the negotiated contract terms that occur within the industry. The range of smelter-refinery operating costs between 20 and 50 pct of the total is probably a good representation, however, the actual distribution within these ranges may vary. Transportation costs could vary if concentrates were shipped by alternative methods or to more distant facilities, and this could have an impact on the overall operating cost of an operation as well.

CAPITAL COSTS

Capital expenditures were calculated for exploration, acquisition, development, mine plant and mine equipment, and for constructing and equipping the mill. The capital expenditures for the different mining and processing facilities include the costs of mobile and stationary equipment, construction, engineering, infrastructure, and working capital.

The initial capital costs for producing or past producing mines, and developed deposits have been depreciated according to when the investment was actually made, and the undepreciated portion was treated as a capital investment in 1982, the first year of the evaluation. Reinvestments will vary according to capacity, length of production life, and age of the facilities.

Initial mine and mill capital investments, based mainly on the Eastern Tennessee and Kentucky zinc deposits, range from $165 to $265 per annual metric ton of capacity, with the majority being just above $200 per metric ton. These ranges are for proposed underground mines that have had no previous development work and will require only minimal expenditures on infrastructure. Infrastructure costs can be quite high in remote, undeveloped areas of the country, and mines that will require substantial infrastructure expenditures, such as those in Alaska, may require up to 2.5 times more initial capital investments per annual metric ton of capacity. Total initial capital investments for some of the undeveloped deposits may range as high as $700 million.

After production parameters and costs for the development of domestic lead and zinc deposits were established, the SAM was used to perform various economic evaluations pertaining to the availability of domestic lead and zinc.

AVAILABILITY OF DOMESTIC RESOURCES

Many factors contribute to the economic status of a deposit. Capital expenditures vary from deposit to deposit depending upon the mining and milling methods used as well as the annual capacity. The cost of transportation and smelting-refining, although often out of the direct control of the mine, will directly impact the total cost of production of the refined product to various degrees. The revenues generated from the byproducts recovered will vary according to the smelter schedule, and the impact of byproduct revenues, or the lack thereof, often determines the make-or-break point for some operations. This is especially true for the NMVT deposits, most of which are located in the Western United States.

PRIMARY LEAD

The 14 mines and deposits evaluated as primary lead operations have in situ demonstrated resources totaling 315.3 million t, which contain 20.4 million t of lead. A total of 17.5 million t of lead could potentially be recovered from these operations, and an additional 5.6 million t of lead could be recovered as a byproduct from primary zinc operations. This results in a total of 23.1 million t of recoverable lead from the mines and deposits evaluated for this study.

Economic evaluations were performed on the 14 primary lead deposits. Nine of these deposits were producing as of January 1, 1982, and the determined weighted average of their total costs was $0.31 per pound of lead. Seven of the nine producers are located in the Southeastern Missouri Lead District and they account for 96 pct (15 million t) of the potentially recoverable lead from the producing operations. The remaining 4 pct (581,000 t) is recoverable from mines with heavy concentrations of precious metals, where the revenues generated from other commodities usually allow for the recovery of lead at little or no additional cost.

A comparison of the weighted average of the total cost of production per pound of recovered lead from currently producing operations to the January 1982 market price of $0.30 per pound, indicates that many of the domestic lead operations can produce competitively over the long-run at current market prices and still achieve the stipulated 15-pct DCFROR. Economic evaluations determined that six of the nine producing operations had long-run total costs of $0.32 per pound of lead, or less. This accounts for 59 pct (10.3 million t) of the lead potentially recoverable from all 14 primary lead operations.

Evaluations performed on the five nonproducing deposits determined a weighted average of their total costs of $0.56 per pound of lead. All but one of these deposits is located in Missouri. Figure 7 shows the total availability curve for the 14 selected primary lead mines and deposits, and illustrates that 94 pct (16.4 million t) of the 17.5 million t of recoverable primary lead is potentially available at or below a long-run total cost of $0.40 per pound.

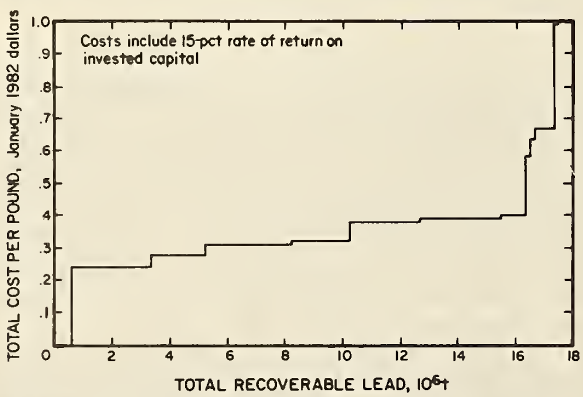


FIGURE 7.—Cost and total availability of primary lead.

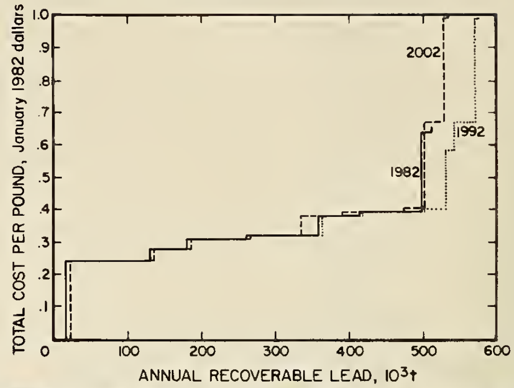


FIGURE 8.—Cost and annual availability of primary lead for selected years.

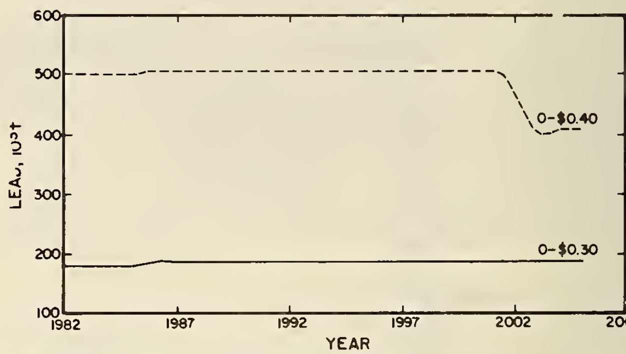


FIGURE 9.—Annual availability of producing primary lead operations for selected price ranges.

Figure 8 shows the annual potential production of lead available for 1982, the base year of the investigation, and for 10 and 20 yr into the future. Under the assumptions made for this investigation, potential production levels could remain fairly constant over the next 20 yr at a price-cost structure between $0.30 and $0.40 per pound of lead. This point is further illustrated by figure 9, which shows the annual production levels for the nine producing operations over the next 20 yr at the price ranges of $0.30 per pound and below, and $0.40 per pound of lead and below. Although not shown on the curve, a small amount of lead (12,000 t) had long-run total costs above $0.40 per pound.

PRIMARY ZINC

The 53 primary zinc mines and deposits include total in situ demonstrated resources of 1.04 billion t containing 49.2 million t of zinc. Potentially, 39.9 million t of zinc could be recovered from the primary zinc deposits, and an additional 2.4 million t could be recovered as a byproduct from primary lead operations. This results in a total of 42.3 million t of potentially recoverable zinc.

There were 16 producing zinc deposits as of January 1, 1982, and economic evaluations determined their total costs at a weighted average of $0.61 per pound of zinc, as compared to the January market price of $0.42 per pound of zinc. This (market price-total cost) difference contributed to a number of operations closing or going on a temporary standby

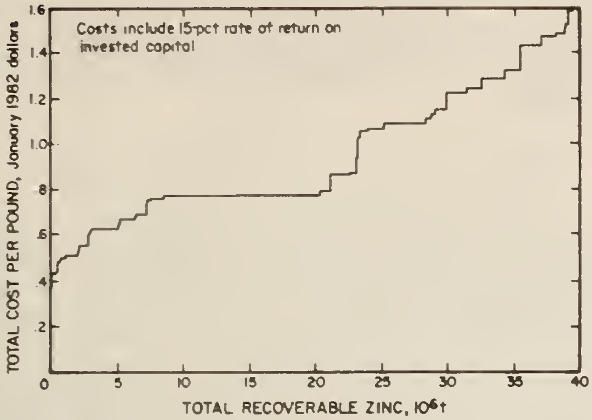


FIGURE 10.—Cost and total availability of primary zinc.

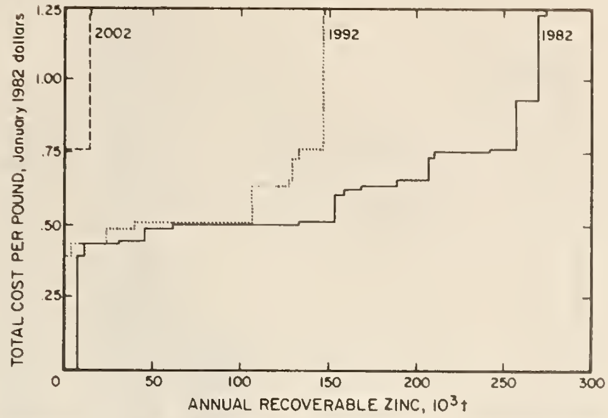


FIGURE 11.—Cost and annual availability of producing primary zinc operations for selected years.

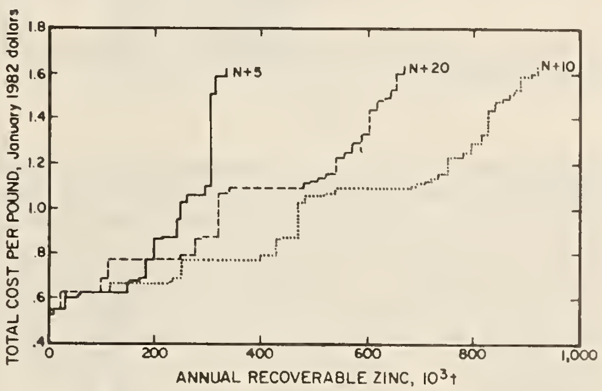


FIGURE 12.—Cost and annual availability of nonproducing primary zinc operations for selected years.

status during 1981 and 1982. Only 1.2 pct (483,000 t) of the potentially recoverable zinc was available below a long-run total cost of $0.44 per pound of zinc. The evaluations for the 37 nonproducers resulted in a weighted average of their total costs of $0.98 per pound of zinc, which is 2.3 times the January 1982 price.

Figure 10 shows that of the nearly 40 million t of recoverable primary zinc, 80 pct (31.9 million t) is potentially recoverable at costs between $0.50 and $1.25 per pound of zinc. Thus the majority of zinc is available from mines and deposits with price-cost structures that are not economic under present conditions. In order for production to begin from many of these operations, there would need to be substantial increases in metal prices, improvements in mining and processing technology, some form of guaranteed financial backing, or possibly a combination of these alternatives.

Figure 11 shows potential annual production levels for producing operations for the base year, 1982, and for 10 and 20 yr into the future. Depletion appears to occur quickly; however, reported resource values for several of the mines, particularly NMVT mines in the western part of the country, could remain fairly constant over the years, and actual depletion of those deposits will probably occur much more slowly than indicated in figure 11. This is because some operations delineate resources sufficient for only a few years of production ahead of their current mining position, thus the resources currently defined appear to become depleted in the next 5 to 10 yr. However, there is a good probability that additional resources exist to allow for continued operation beyond the reported 5 to 10 yr.

Figure 12 shows the proposed potential annual production levels for nonproducing mines and deposits for 5, 10, and 20 yr into the future. Production levels were attained assuming that all preproduction developing work was to have begun in 1982 (base year, N), and thus a number of operations would have come on line in the next 5 yr and could begin to pick up for the decline experienced by the current producing operations. As seen in this curve, annual production levels from primary zinc operations would peak in 10 yr. Thereafter, production would begin to decline unless additional resources were located, technologic improvements were made to allow for the processing of lower grade material, or other alternative sources were developed, such as the recovery of metals from geothermal brines that is currently being tested by the Bureau (*25*). It should be kept in mind that the total cost of production for most of the nonproducing operations is well above current economic levels and actual production from these mines and deposits will depend on a number of economic and technologic factors, and growth and declines in production rates will probably be much more gradual.

SENSITIVITY ANALYSES

Production costs for primary lead and zinc are influenced by a number of factors. The following sections will discuss the impact that varying the stipulated 15-pct DCFROR has on the availability of lead and zinc, as well as the impact of fluctuating byproduct prices, and the impact of increased smelter charges.

IMPACT OF VARYING DISCOUNTED-CASH-FLOW RATE OF RETURN

As previously defined, the DCFROR is the rate that makes the present value of all current and future revenues equal to the present value of all current and future costs. For this study, a constant minimum rate of return of 15 pct was specified. This rate was considered sufficient to attract new capital to the industry. In order to show the impact that the 15-pct DCFROR had on the long-run total costs and availability of primary lead and zinc from the 67 mines and deposits investigated, they were evaluated at a breakeven (0-pct) DCFROR where all investments are recovered but no return was realized.

Figure 13 illustrates the differences between the availability curves for primary lead at the breakeven and

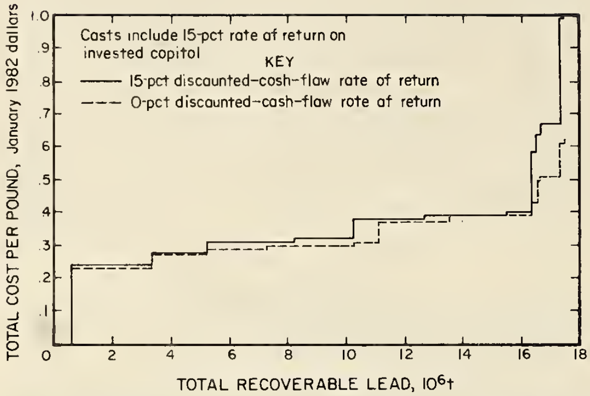


FIGURE 13.—Cost and total availability of primary lead at 0-pct and 15-pct DCFROR.

15-pct DCFROR. According to the results, specifying the DCFROR of 15 pct had little impact upon the total cost of production for the lead operations. It should be noted that 9 of 16 of the primary lead operations are currently producing. The initial capital for the producing operations has been recovered, leaving a much smaller investment base earning the specified DCFROR. Conversely, note the increase in the total costs of the 15-pct DCFROR curve on the right side of the curve where currently nonproducing deposits are represented.

Figure 14 shows that achieving the specified 15-pct DCFROR had a greater effect on the total costs for primary zinc operations. The majority of recoverable primary zinc could be available between $0.40 and $0.75 at the breakeven level, which is substantially different from the $0.50 to $1.25 range required at a 15-pct level. However, it should be stressed that 37 of the 53 primary zinc mines and deposits are not currently producing and most would have large initial capital investments to recover, and consequently, a relatively large investment base earning the specified DCFROR.

In summary, the primary zinc operations showed the largest increase in total costs when attaining the specified 15-pct DCFROR. The 37 nonproducing zinc operations had significantly lower price-cost structures at the breakeven (0-pct) DCFROR level than at the specified 15-pct level. Nine of the fourteen primary lead operations were producing at the time of this evaluation and their price-cost structures were not impacted significantly by varying the rate of return on investment.

IMPACT OF BYPRODUCT PRICE CHANGES

The presence of recoverable byproducts enhances the economic availability of the primary product. In order to show the impact of changes in byproduct revenues upon the total cost of the primary commodity, a sensitivity analysis was performed holding all cost constant and substituting average 1980 commodity prices for the evaluation value prices of January 1982. For the purposes of this evaluation, all recoverable byproducts were sold and byproduct revenue credits were applied according to the generalized smelter schedule discussed earlier. Average 1980 prices were used because they represent wide price fluctuations, with some commodity prices being higher and others lower than the January 1982 prices, some by significant amounts. Any other set of alternative prices would impact individual mines differently, but the importance of byproduct prices can be seen clearly in this analysis. Table 18 lists the January 1982 and the average 1980 prices that were used in the analysis. Note that while zinc prices have remained relatively constant over the years, they were down in 1980. Lead prices, on the other hand, fluctuate widely and were relatively high during 1980.

Figures 15 and 16 show the changes in the total cost of production, after credit for byproduct revenues, that occur when average 1980 commodity prices are substituted for January 1982 prices. The total cost for primary zinc and lead showed the largest increase from average 1980 to January 1982 commodity prices for those operations in NMVT deposits that recovered significant quantities of byproducts or

Table 18.—Commodity prices used in byproduct sensitivity analyses

Commodity	January 1982	Average 1980
Barite.................. per ton..	$105.00	$70.00
Cadmium................ per lb..	1.40	2.84
Copper.................. per lb..	.79	1.00
Fluorspar................ per t..	165.00	109.00
Gold.................. per tr oz..	384.12	596.00
Iron (pellets) .... per ltu..	.81	.75
Lead.................... per lb..	.30	.42
Limestone................ per t..	4.13	3.35
Silver................ per tr oz..	8.03	18.00
Zinc .... per lb..	.42	.37

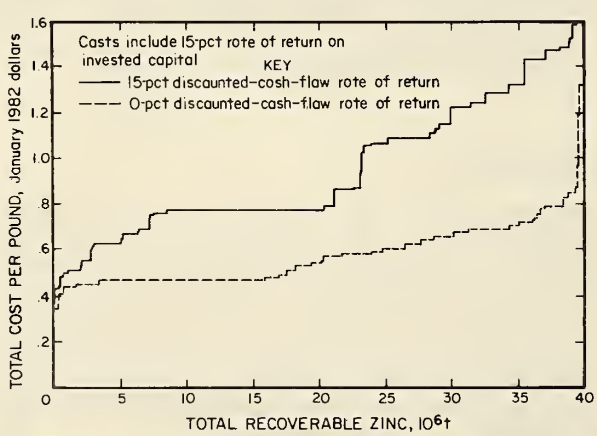


FIGURE 14.—Cost and total availability of primary zinc at 0-pct and 15-pct DCFROR.

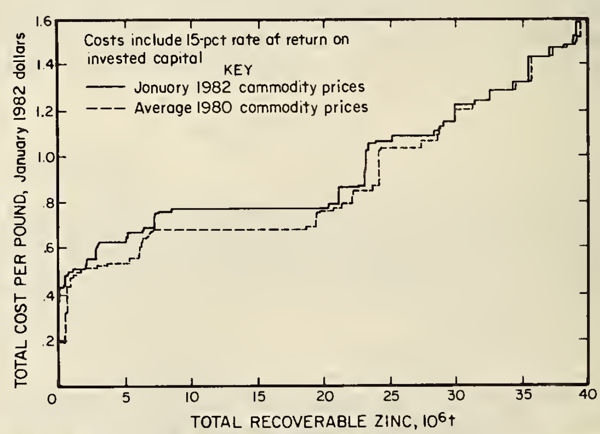


FIGURE 15.—Cost and total availability of primary zinc using average 1980 and January 1982 commodity prices.

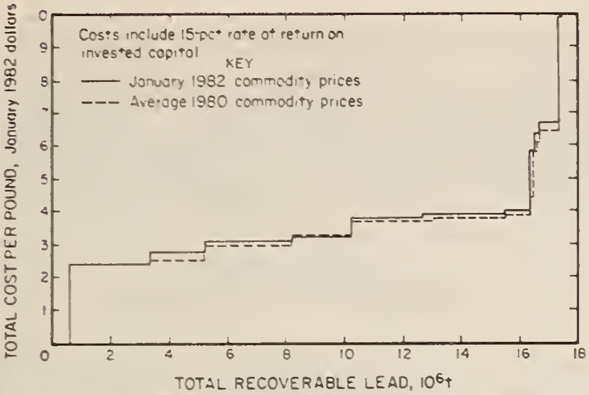


FIGURE 16.—Cost and total availability of primary lead using average 1980 and January 1982 commodity prices.

coproducts such as copper, silver, and/or gold, which were experiencing higher prices during 1980 than in January 1982.

Figure 15 illustrates that the greatest impact from byproduct revenues occurs in those primary zinc operations with a total cost between $0.50 and $1, and most of the tonnage from these operations is located in NMVT deposits. Approximately 67 pct of the operations in this price range were producing when the byproduct prices were higher, however, as of January 1, 1982, only 37 pct of them were still producing. Since January 1982, a number of additional mines have gone on standby status or have closed indefinitely.

Figure 16 indicates that byproduct or coproduct prices have very little impact upon the total cost of production for most primary lead operations. This is because 11 of the 14 primary lead operations are located in MVT deposits and generally recover only a minor amount of byproducts.

A decrease in byproduct revenues resulted for some of the primary zinc operations when average 1980 prices were substituted for the commodities such as iron, fluorite, barite, and agricultural limestone, which have increased since 1980. This decrease in byproduct revenues caused an increase in the total cost of production for zinc operations that recovered those commodities. The price for zinc was also down in 1980, and the total cost of production also increased for two of the primary lead operations that recovered significant amounts of zinc. These cost reversals are shown in the bar graphs in figures 17 and 18, which illustrate the amount of byproduct revenues generated at 1980 and 1982 commodity prices in terms of dollars per pound of recovered primary commodity. Note that not all operations are represented in these figures; those without byproducts and those with no change in revenues were not included.

It should be kept in mind that the evaluations were done at a specific point in time using long-run constant costs and commodity prices, and therefore reflect the relative costs and commodity prices that prevailed at that time. For deposits with recoverable byproducts, sensitivity analyses are very important to a complete evaluation.

The total cost for an undeveloped primary zinc deposit located in a NMVT deposit and recovering precious metals as byproducts, dropped an average of $0.10 per pound of zinc when average 1980 commodity prices were substituted. Primary lead operations are mostly located in MVT deposits and recover only small amounts of byproducts from these deposits. The total cost of production for some of the primary lead operations dropped $0.02 to $0.03 per pound of lead and the total cost for the operations that recovered significant quantities of zinc actually increased by a cent or two. The variations shown by this evaluation could have had other results with a different set of commodity prices, and variations in commodity prices in the future may affect the economic attractiveness of a number of the mines and deposits evaluated.

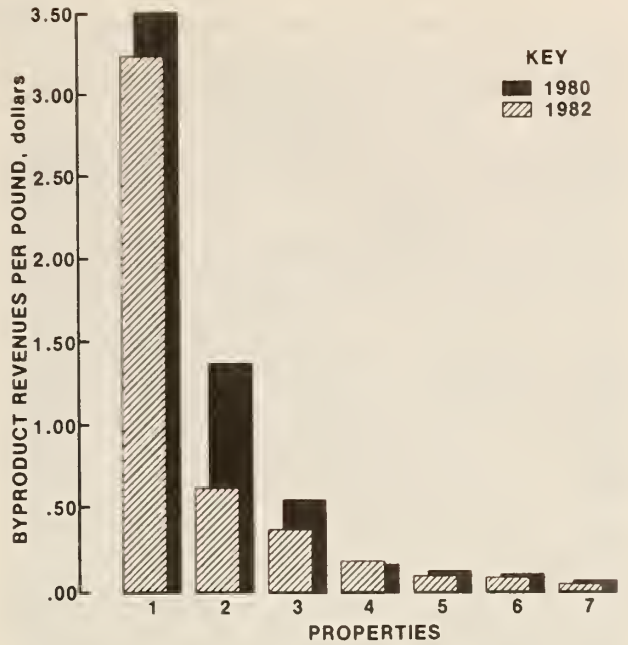


FIGURE 17.—Primary lead byproduct revenues below $3.50 per pound of recovered lead, for selected operations, at average 1980 and January 1982 commodity prices.

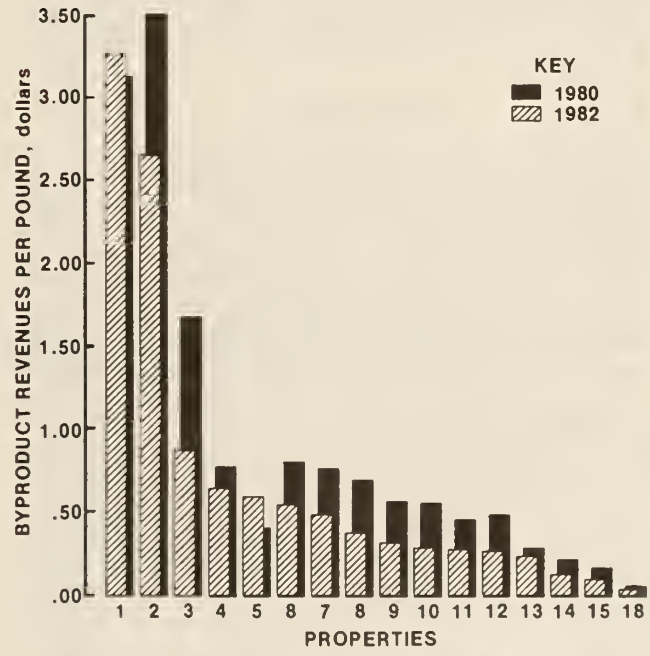


FIGURE 18.—Primary zinc byproduct revenues below $3.50 per pound of recovered zinc, for selected operations, at average 1980 and January 1982 commodity prices.

IMPACT OF INCREASED POSTMILL PROCESSING CHARGES

Postmill processing charges are difficult to predict, but are crucial in a property evaluation. As discussed in the "Operating Costs" section, smelter charges ranged from 20 to 50 pct of the total operating cost for 62 of the 67 operations evaluated. This area of cost is subject to change as a result of supply and demand, and the smelter charges are

often out of the direct control of the mining operation itself. Also, since a common smelter schedule was used for the evaluations, it is possible that smelting costs for any particular operation could vary substantially from that assumed for the evaluation. For these reasons, the smelter treatment charges were arbitrarily increased by 50 pct for all operations in order to analyze the impact on the long-run total costs and availability of primary lead and zinc from the mines and deposits included in this evaluation.

Figures 19 and 20 illustrate that the increased smelter charges increased the total cost of production fairly equally for most operations. The lead operations were a little more sensitive overall than the zinc operations, because the majority of lead operations are producing and capital costs are a lower percentage of total costs, while smelter treatment costs are a higher percentage, thus making producing operations more sensitive to change than their nonproducing counterparts. The average total cost of production for lead operations increased between $0.07 and $0.09 per pound of lead. On a percentage of total cost basis, the producers would feel the greater impact. The overall increase in total cost is significant (23 to 29 pct) when compared to the January 1982 market price of $0.30 per pound of lead. The January market price of zinc was $0.42 per pound and the increase caused by the higher smelter costs averaged between 24 and 36 pct of the market price ($0.10 to $0.15 per pound of recovered zinc), and again the producers would feel the greater impact.

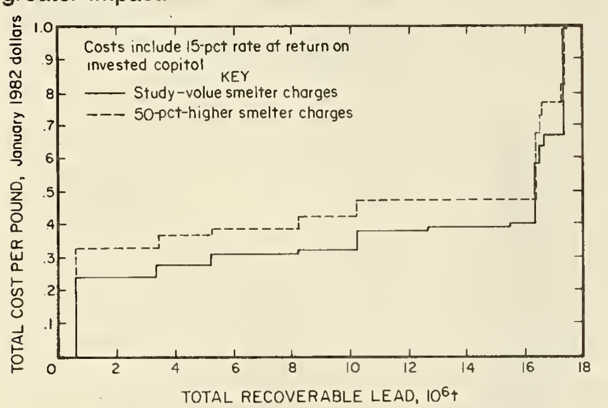


FIGURE 19.—Cost and total availability of primary lead using the study value and 50 pct higher smelter treatment charges.

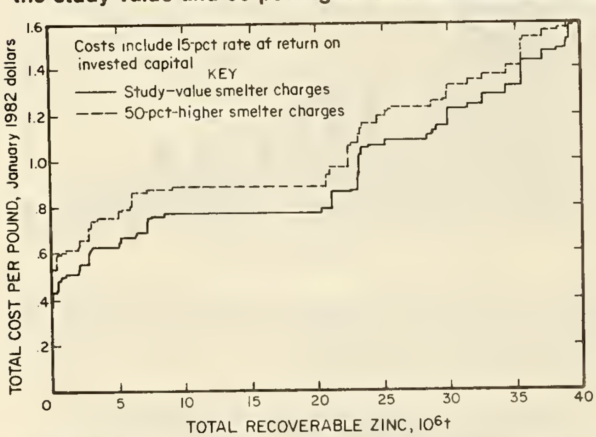


FIGURE 20.—Cost and total availability of primary zinc using the study value and 50 pct higher smelter treatment charges.

In summary, because postmill processing charges are usually not in the direct control of the mining company, the actual cost to each operation will vary according to a number of factors. The producing operations were more sensitive to change in smelter treatment charges than their nonproducing counterparts. The common smelter schedule used for this evaluation should be looked on as reference base, with actual terms varying above and below the scheduled rates.

SUMMARY OF SENSITIVITY ANALYSES

Table 19 illustrates the results of the three sensitivity analyses by showing the changes in the weighted average of the total costs for primary lead, by the nine producers, five nonproducers, and the total for the 14 sites for each of the sensitivity factors analyzed. Table 20 summarizes the same information for primary zinc operations. These tables show that producing operations were impacted the most by increased smelter charges, and operations not in production as of the study date were influenced most by the specified DCFROR. While byproduct prices were crucial for some of the individual operations, on average they were found to be not as influential as the other two factors in the sensitivity analyses.

The majority of primary lead operations were in production, and lead was influenced most by the smelter charge increase. Zinc operations, on the other hand, were mostly nonproducers, and also contained a higher percentage of NMVT deposits with byproduct revenues. For these reasons, primary zinc operations were most sensitive to the specified DCFROR, and also were far more sensitive to increased byproduct revenues than were the lead operations, most of which are located in MVT deposits.

Table 19.—Weighted average of total cost of production for primary lead operations

(Cents per pound of lead)

Cost	Producers[1]	Nonproducers[2]	Weighted average
At 15-pct DCFROR	31.1	56.1	33.9
At break-even (0-pct) DCFROR	30.4	42.6	31.8
Using average 1980 byproduct prices at 15-pct DCFROR	30.8	54.8	33.4
Using 50-pct-higher smelter charges at 15-pct DCFROR	40.2	65.0	42.9

[1] 9 producing operations as of January 1, 1982.
[2] 5 nonproducing operations include past producing mines, as well as developed and undeveloped deposits.

Table 20.—Weighted average of total cost of production for primary zinc operations

(Cents per pound of zinc)

Cost	Producers[1]	Nonproducers[2]	Weighted average
At 15-pct DCFROR	61.0	98.0	94.1
At break-even (0-pct) DCFROR	56.7	57.5	57.4
Using average 1980 byproduct prices at 15-pct DCFROR	61.3	91.7	88.5
Using 50-pct-higher smelter charges at 15-pct DCFROR	71.2	110.0	106.3

[1] 16 producing operations as of January 1, 1982.
[2] 37 nonproducing operations include past producing mines, as well as developed and undeveloped deposits.

SUMMARY

Recent economic trends of higher costs and declining metal prices have caused the closure of several mines and smelting-refining operations during the last few years. The U.S. smelters operate at a cost disadvantage relative to many foreign smelters, due partly to a substantial difference in governmental policies among countries that produce lead and zinc for worldwide consumption. Many governments support their domestic nonferrous metals industries, while U.S. policies such as price controls and environmental regulations have put many domestic producers at a cost disadvantage (*7*).

DEPOSIT CLASSIFICATIONS

Of the 67 sites evaluated for this study, 43 occur in Mississippi Valley-type (MVT) deposits, which are members of the strata-bound carbonate-hosted category (*22*). The other 24 mines and deposits occur in all of the remaining deposit types, referred to here as non-Mississippi Valley-type (NMVT) deposits. The 43 MVT sites account for approximately 98 pct of the total in situ primary lead resources and 67 pct of the total in situ primary zinc resources.

The NMVT deposits evaluated contain a higher value of recoverable byproducts than do the MVT deposits. Higher byproduct revenues generated from NMVT deposits offset a portion of the production costs and could make the NMVT deposits more attractive for future development. Revenues generated by byproduct gold, silver, and copper may be substantial, and in some cases may be the determining factor as to whether a particular deposit is exploited, or whether a partcular mine remains open. However, not all deposits, regardless of MVT or NMVT classification, contain gold, silver, or copper.

There is also a difference in mining methods and costs that exist between MVT and NMVT deposits. The majority of the MVT deposits are mined using some form of room-and-pillar mining, with operating costs that are generally lower than those methods used to mine the NMVT deposits.

PRIMARY LEAD

The current (January 1982) price-cost structure for primary lead, as shown in this investigation, indicates that the majority of operations were producing competitively, as 59 pct (10.3 million t) of all recoverable primary lead was available at or below a long-run total cost of $0.32 per pound of lead. The total cost of production for the nine producing lead mines was determined at a weighted average of $0.31 per pound of lead, and the January 1982 market price for lead was $0.30 per pound. Economic evaluations performed on the mines and deposits not in production as of January 1, 1982, had a weighted average for their total costs of production of $0.56 per pound of lead.

Included in this investigation was a total of 315.3 million t of in situ primary lead resources containing 20.4 million t of lead. Potentially, 17.5 million t of lead could be recovered from the 14 primary lead operations, and an additional 5.5 million t of lead could potentially be recovered as a byproduct from 20 of the primary zinc operations. Thus, a total of 23 million t of lead could potentially be recovered from 34 operations, and the cumulative demand through the year 2000 has been forecasted at 13.3 million t of recovered lead (*18*). Production levels for primary lead could remain relatively constant for the next 20 yr for the price-cost structure between $0.30 and $0.40 per pound of lead, assuming continued production from already producing operations and development of additional deposits beginning in January 1982.

SENSITIVITY ANALYSES RESULTS FOR PRIMARY LEAD

Sensitivity analyses were performed on the 14 primary lead operations to determine the impact of several factors on the total cost of production. These analyses included the impact of the stipulated 15-pct DCFROR versus a breakeven (0-pct) DCFROR, the impact of byproduct revenues using average 1980 commodity prices versus the investigation values of January 1982 prices, and the impact of increasing smelter charges by 50 pct.

Nine of the fourteen primary lead operations were producing, and these producing operations showed little effect from the DCFROR sensitivity analysis because their initial capital investments had been recovered. Increased byproduct prices also had little effect on the availability of primary lead, as 11 of the 14 sites were located in MVT deposits, which do not contain the high amounts of byproducts that NMVT deposits contain.

The analyses revealed that only increased smelter charges had any real impact on the cost of production, and again this is because the majority of the lead operations were producing. Operating costs make up a larger percentage of the total cost of production for producing operations, and smelter costs are a substantial portion of these operating costs, between 20 and 50 pct for most operations. Increasing smelter charges by 50 pct increased the weighted average of the total cost for producing operations by nearly 30 pct, from $0.31 to $0.40 per pound of lead, while the long-run total cost for the nonproducing operations increased about 16 pct, from $0.56 to $0.65 per pound.

PRIMARY ZINC

The 53 primary zinc mines and deposits include 1.04 billion t of in situ demonstrated resources containing 49.2 million t of zinc. The total potentially recoverable zinc is 42.3 million t from the mines and deposits evaluated, including the 2.4 million t of byproduct zinc available from the primary lead resources. Most of the resources are contained in mines and undeveloped deposits with price-cost structures that are higher than the January 1982 market price of $0.42 per pound of zinc, only 1.4 pct (555,000 t) of the total recoverable zinc from primary zinc operations was available at or below a long-run total cost of $0.44 per pound of zinc.

There were 16 producing zinc mines as of January 1, 1982, and economic evaluations determined a weighted average of the total cost of $0.61 per pound of zinc. Due in part to the price-cost difference between these operations and the January market price, a number of mines closed or went on temporary standby status during 1982. The evaluations for the 37 nonproducers resulted in a weighted average of the total cost of $0.98 per pound of zinc, which is more than 2.3 times the January 1982 market price of $0.42 per pound of zinc.

The nearly 40 million t of recoverable zinc potentially available from the domestic primary zinc resources is more than adequate to meet the cumulative projected demand of 10.7 million t of refined zinc through the year 2000, but the majority of the resources are available from currently nonproducing mines and deposits (*20*). If preproduction for all nonproducing primary zinc deposits were to have begun in 1982, and current producers were to operate at full capacity, total production would peak in 10 yr. After 10 yr, a number of currently producing and smaller nonproducing operations would begin to run out of resources and production levels would drop as depletion occurred. Actual production from the currently nonproducing mines and deposits would depend

on a number of economic and technologic factors, and either growth or declines in production rates would be much more gradual than assumed for this analysis.

SENSITIVITY ANALYSES RESULTS FOR PRIMARY ZINC

Sensitivity analyses were also performed on the 53 primary zinc operations to determine the impact of several factors on the total cost of production. These analyses included the impact of the stipulated 15-pct DCFROR versus a breakeven (0-pct) DCFROR, the impact of byproduct revenues using average 1980 commodity prices versus the evaluation values of January 1982 prices, and the impact of increasing smelter charges by 50 pct.

The analyses revealed that the primary zinc operations appear to be more sensitive to changes in the assumptions underlying the evaluations than the lead operations. The zinc operations were quite sensitive to the level of prespecified DCFROR because 37 of the 53 operations were nonproducers at the time of the evaluation.

Byproduct revenues were also important to the economics of the zinc operations. A number of the primary zinc operations are located in NMVT deposits, and they depend on the revenues generated from byproducts to help meet the cost of production. As a result of using byproduct credits calculated at average 1980 commodity prices instead of January 1982 prices, the weighted average of the total costs for all zinc operations decreased by about 6 pct. The range of change in the individual mine's total cost due to byproduct credits was quite wide, with up to 85 pct higher total costs at January 1982 prices than at average 1980 prices.

Although not nearly as important on average for zinc as for lead, a 50-pct increase in smelter charges still raised the weighted average of the long-run total cost of production for producing operations from $0.61 to $0.71 per pound of zinc (17 pct). The weighted average of the total cost of production for nonproducing operations rose from $0.98 to $1.10 per pound (12 pct).

DOMESTIC SMELTER CAPACITY

Domestic zinc smelter capacity has been declining over the years, and this may be as critical to the U.S. position of self-sufficiency as the amount of domestic resources available. The 5-yr average (1977-81) domestic mine concentrate production levels were 94 pct of primary (refined) lead production, and the import reliance was approximately 4 pct. Zinc, however, had average domestic mine concentrate production levels at 82 pct of the domestic refined (slab) zinc levels, but import reliance amounted to 62 pct.

The domestic lead industry was found to be competitive at January 1982 market prices. The large, efficient, and often automated lead and secondary lead industry is well enough developed to provide over half of the current supply requirements. However, closure of the Bunker Hill smelter-refinery complex as well as overcapacity problems at a number of the domestic primary and secondary processing facilities may indicate that the domestic smelting-refining industry may not be able to maintain its current competitive position. A potential decline in capacity could be partially attributed to declining metal prices and costly environmental regulations that are more stringent domestically than in some of the other countries that compete with the United States (*6-8*).

The current refinery capacity of 595,000 t of lead per year is sufficient, but forecasts project that an additional 105,000 t of annual capacity will be needed to meet demand requirements in the year 2000 if import levels of refined lead are to remain at their current low levels, or 205,000 t of additional capacity would be required to attain primary (refined) lead self-sufficiency (*18*). Additional capacity could be required if current capacity levels decline. The cumulative demand through the year 2000 is forecast at 13.3 million t of lead. Although production levels would have to be increased, the resources evaluated could recover an estimated 17.5 million t of lead over their projected lives, and 90 pct (16.4 million t) could potentially be recovered at or below a cost of $0.40 per pound of lead.

The decline in domestic zinc self-sufficiency over the years has been due to the low zinc grades of domestic mines and the increasing cost of producing from them. The market value of zinc has not kept up with the increasing cost of production, and the result has been the closure of a number of domestic zinc mining operations (*8, 12*).

Projected annual demand for refined slab zinc through the year 2000 has been forecasted at 1.05 million t, while current capacity is only 390,000 t (*20*). The projected annual domestic mine capacity has been estimated at approximately 640,500 t of zinc based on continuing high import dependence; however, maintaining the current capacity could be difficult in view of the low utilization levels that are precipitating a number of cutbacks and closures in the domestic zinc industry.

With the supply of domestic zinc feed material declining, domestic smelters have had to import concentrates to meet their needs, or shut down (*8-9*). This has been an expensive alternative because many countries will produce and export the final products, such as slab zinc, at prices below their U.S. counterparts who have to add the cost of importing foreign concentrates to their cost of processing. The combinations of domestic zinc smelters having to purchase foreign concentrates, the high cost of modernizing and operating the older facilities that predominate in the domestic zinc smelting industry, and the cost of environmental regulations, particularly for the lead industry, have all presented serious obstacles to the maintenance of the domestic lead and zinc industries.

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APPENDIX A.—DOMESTIC LEAD AND ZINC OWNERSHIP INFORMATION

Table A-1.—Domestic lead ownership information

State and property	*Ownership*
Colorado: Bulldog	Homestake Mining.
Idaho: Lucky Friday	Hecla Mining Co.
Missouri:	
Boss-Bixby	Getty Oil, AZCON, Hanna Mining.
Brushy Creek Division	St. Joe Minerals Corp.
Buick	AMAX Lead, Homestake Lead.
Fletcher	St. Joe Minerals Corp.
Higdon-Bonne Terre	Bunker Hill, St. Joe Minerals Corp.
Missouri—Con.	
Indian Creek	St. Joe Minerals Corp.
Magmont	COMINCO AM., Dresser Ind.
Milliken	Kennecott Copper Corp.
Viburnum No. 28 and No. 29	St. Joe Minerals Corp.
Viburnum No. 35	Do.
West Fork	ASARCO.
Utah: Ontario	Noranda, United Park City Mines.

Table A-2.—Domestic zinc ownership information

State and property	*Ownership*
Alaska:	
Arctic	Kennecott Copper Corp.
Greens Creek	Noranda and others.
Lik	Houston Oil & Minerals, GCO.
Red Dog	COMINCO.
Colorado:	
Black Cloud	ASARCO, Resurrection.
Idarado	Newmont Mining.
Sunnyside	Standard Metals.
Idaho:	
Bunker Hill	Bunker Hill, Gulf Resources.
Star Morning	Bunker Hill, Hecla Mining.
Illinois: Minerva No. 1-Spivey	Inverness Mining.
Kentucky:	
Burkesville Project	COMINCO, ASARCO, and others.
Fountain Run	St. Joe Minerals Corp.
Maine:	
Bald Mountain	Superior Oil Co.
Kerr American-Blue Hill	Kerr American Inc., Black Hawk.
Montana: Butte District Zinc	Anaconda Copper Corp.
Nevada:	
Ruby Hill Mine	Ruby Hill, Hecla, and others.
Ward Mountain	Gulf Oil, Silver King Mines.
New Jersey: Sterling	New Jersey Zinc Co.
New Mexico: Pinos Altos	Boliden Minerals, Exxon Minerals Corp.
New York:	
Balmat	St. Joe Zinc.
Pierrepont	Do.
Pennsylvania: Friedensville Mine	New Jersey Zinc Co.
Tennessee:	
Beaver Creek	Do.
Big War Creek	Do.
Tennessee—Con.	
Carthage Property	St. Joe Minerals Corp. and others.
Copperhill	Cities Services Corp.
Coy	ASARCO Inc.
Cub Creek	New Jersey Zinc and others.
Cumberland	Jersey Miniere Zinc Co.
Cumberland Deposit	W.
Cumberland Property	St. Joe Minerals and others.
East Gainesboro	W.
Gainesboro	New Jersey Zinc and others.
Gordonsville-Elmwood	Jersey Miniere Zinc Co.
Hartsville	W.
Hartsville Area	COMINCO American, NL Industries.
Idol	New Jersey Zinc Co.
Immel	ASARCO Inc.
Jefferson City Mine	New Jersey Zinc Co.
Lost Creek	Do.
New Market	ASARCO Inc.
Pall Mall	ASARCO Inc. and others.
Right Fork	ASARCO Inc.
Roaring River	New Jersey Zinc Co., AMAX Inc.
Stonewall	Jersey Miniere Zinc Co.
Young	ASARCO Inc.
Zinc Mine	US Steel Corp.
Washington:	
Boundary Dam-Metaline Falls	Metaline, Washington Resources.
Washington Zinc Unit	Callahan Mining Corp. and others.
Wisconsin:	
Crandon	Exxon Minerals Corp.
Crawhall-Elmo No. 3	Inspiration Mines.
Pelican River	Noranda Corp.
Shullsburg-Bearhole	Inspiration Mines.

W Withheld, company proprietary information.

APPENDIX B.—MINES AND DEPOSITS EXCLUDED FROM THIS STUDY

The mines and deposits listed below were excluded from this study because they did not contain sufficient quantities of lead and/or zinc to meet the criteria established for this evaluation. The criteria are explained in the "Introduction" section.

State	*Property name*
Alaska	Ground Hog Basin.
	Picnic Creek.
	Sum Dum.
	Sun Group.
Arizona	Bruce.
Colorado	Camp Bird.
	Eagle.
	Emperius.
Idaho	Couer Project.
	Galena
Missouri	La Motte.
	Madison.
Nevada	Caselton.
	Pan American.
	Prince.
New Mexico	Ground Hog.
	Hanover (Empire).
	Lynchburg.
	Princess.
New York	Edwards.
	Hyatt.
Tennessee	Chucky Pike.
	Shiloh Prospect.
Utah	Burgin.
	Deer Trail.
	Lakeview.
	Mammoth.
	Mayflower.
	Pete's Tunnel.
	Spelter Tunnel.
	Tintic Standard.
	Trout Creek.
	U.S. and Lark.
	Volunteer Gulch Incline.
Virginia	Austinville-Ivanhoe.
Washington	Deep Creek.
	Pend Orielle.

APPENDIX C.—GEOLOGY NARRATIVES BY STATE

The reader should refer to tables 4 and 6 in the main text for individual deposit resource tonnages and grades.

ALASKA

The Arctic massive sulfide deposit occurs in the Ambler Mining District in the Southwestern Brooks Range near the center of a northwest-trending belt of Paleozoic schistose rocks that outcrop on the Kalurivik arch. The trough-shaped stratiform volcanogenic deposit lies on the southwest limb of the arch. Major host rock units at the Arctic deposit are metarhyolites, metatuffs, and graphitic schists (*21*).[1] Zinc and copper-bearing minerals are dominant, with lead and silver-bearing minerals occurring in minor amounts. The district is potentially important as other massive sulfide deposits have been discovered since 1965. The Arctic deposit, as well as the other three Alaska deposits are non-Mississippi Valley-type (NMVT) deposits.

The Greens Creek deposit is located in a National Monument in the northeastern part of Admiralty Island. It is a stratabound massive sulfide deposit occurring on the limb of an overturned anticline in an area of complexly folded volcanic rocks. The mineralogy is very complex, and several different ore types are present. Zinc, lead, gold, and silver-bearing minerals are the most important minerals.

The Red Dog and Lik deposits occur in the Western Brooks Range in Paleozoic sedimentary rocks that are part of a complex series of thrust sheets. The deposits are stratiform massive sulfide deposits and lie within a shale unit (*21*). Zinc is dominant, with lesser amounts of lead and silver-bearing minerals occurring in the deposits. Not much exploration had been done in the Western Brooks Range prior to 1970, but recent discoveries indicate that the area may be a major mineral province. In fact, the Red Dog deposit is one of the largest and richest zinc deposits known in the world.

Although Alaska is an important potential producer of minerals, development of its resources is hampered by (1) a lack of infrastructure and its associated high cost, (2) access and transportation limitations, (3) restrictive land classification, and (4) the harsh climate, which causes operational difficulties and potentially shortened mining seasons.

COLORADO

Three of the Colorado properties evaluated, the Sunnyside, Idarado, and Bulldog Mines, are located in the San Juan Mountains of southwest Colorado, an area covered by late Tertiary volcanics. The majority of the minerals in this area, including that of the three mines, occur marginal (adjacent) to calderas in faults and fractures, but "important ore bodies have been found in chimneys, mantos, stockworks, and volcanic pipes" (*26*).

Mineralized vein systems occasionally run for several kilometers and "may cut the entire volcanic series and the underlying sediments" (*27*). The underlying sediments also contain mineralized zones, and the amount of ore of this type still undiscovered in the area may be large because the sediments may lie under more than a kilometer of volcanic rock (*26*).

At two of the sites, the precious metal content of the ores is much more imporant than that of lead and zinc. Although the proportions of specific minerals at each of the deposits vary considerably, the ores consist typically of lead, zinc, and copper minerals, along with significant amounts of silver and gold-bearing minerals.

[1] Italicized numbers in parentheses refer to items in the list of references preceding the appendixes

The Black Cloud Mine is located in central Colorado near Leadville, in an area covered by Paleozoic and Mesozoic sedimentary rocks that have been tilted, faulted, and fractured. Most of the Tertiary minerals in the western part of the Leadville District in the vicinity of the Black Cloud Mine occur in replacement deposits in the Pre-Pennsylvanian Leadville and Dryer Dolomites. Significant deposits of minerals also occur in fault zones. Lead, copper, gold, zinc, and silver-bearing minerals are the major commercial minerals in the area. All Colorado sites occur in NMVT deposits.

IDAHO

The Lucky Friday, Star Morning, and Bunker Hill Mines are located in the Coeur d'Alene Mining District in metasedimentary rocks of the Precambrian Belt Supergroup. Many of the mines in the district lie near the Osburn Fault, a prominent structure that cuts through the area in a westerly direction.

Minerals occur primarily in replacement veins, but mineral types are not uniform throughout the district. Economic minerals occur in the upper unit of the Revett quartzite, which is the horizon in which most of the mining has occurred. Complex fault systems related to the Osburn Fault occur throughout the area and "mineralization is most intense in the more faulted portions of the area, although the major faults are themselves essentially barren" (*26*).

There is a very high probability that additional resources of lead and zinc exist in addition to those used for this evaluation because the vein structures continue at depth. It should be noted that mines in the area do not explore for additional resources in excess of about 5 yr worth of production. This has been the standard practice for many years and the published resource figures do not reflect the true potential of the district.

ILLINOIS

The Minerva No. 1 and Spivey Mines are located in the Illinois-Kentucky Fluorspar District, an area covering approximately 1,100 sq km and one of the most productive fluorspar districts in the world. The sites are in Mississippi Valley-type (MVT) deposits and occur in Mississippian sediments that have been deformed into a northwest-trending arch and then faulted. Most of the faults are steeply dipping, trend northeast, and are continuous for several kilometers.

The deposits occur as either bedded replacement deposits (similar to the Minerva No. 1 Mine) or as vein deposits associated with the northeast-trending faults (similar to the Spivey Mine). The bedded deposits occur mostly in the top of the Ste. Genevieve Limestone, the Spar Mountain Sandstone Member of the Ste. Genevieve Limestones, and the top of the Downeys Bluff Limestone. The vein deposits are not as stratigraphically restricted as the bedded deposits, may be up to 10 m in width, and can be composed of pure fluorite. The important minerals are fluorite, sphalerite, galena, and barite. Lead and zinc resources, in addition to those evaluated, are associated with present and potential fluorite production from this district, but no estimate of the total amount available from this source was made.

MAINE

The Bald Mountain massive sulfide deposit is located in a belt of metamorphosed volcanic and sedimentary rocks that stretches from New Hampshire northeasterly into New

Brunswick, Canada. Copper and zinc occur in selected beds of siliceous rock that have a minor carbonate content. Gold and silver occur in minor amounts. Exploration in the area has increased substantially within the last 10 yr, and additional deposits may be discovered in the belt in the future.

The Kerramerican-Blue Hill property is located in an area of southeast Maine where the Paleozoic Ellsworth Schist comes in contact with granitic intrusions of Silurian or Devonian age. During the late 1800's some copper, lead, zinc, and a small amount of silver were extracted from mines in the region before mining was discontinued owing to low ore grades. At the Kerramerican property the minerals occur in a relatively pure quartzite. Zinc materials are the most important, and occur in long, thin tabular bodies on the limb of a syncline. Chalcopyrite occurs throughout the deposit, but bodies high in copper are less frequent and much smaller than those containing zinc. All of the Maine sites occur in NMVT deposits.

MISSOURI

The lead deposits in southeastern Missouri occur on the flanks of a dome in a series of Upper Cambrian sedimentary rocks that encircle the St. Francois Mountains. Although there is some mineralized rock in other Paleozoic strata, most of the ore bodies occur in the brown dolomite of the Bonne Terre Formation.

Ore deposits are strataform and the minerals generally occur either in replacement or disseminated deposits, veinlets, or fillings in open spaces. Although the deposits consist mostly of lead-bearing minerals, enough zinc is present for six of the seven producing mines to be included among the top zinc producers in the United States. Small amounts of nickel, cobalt, and cadmium also occur in the deposits.

The Old Lead Belt, an area of extensive production in the past, is almost mined out, and development is now centered in the more recently discovered Viburnum Trend. All of the Missouri sites evaluated are located in the trend except the Higdon and Bonne Terre Mines, which are in the Old Lead Belt. Figure C-1 shows the locations of mines and deposits along the Viburnum Trend. Although the Indian Creek Mine is not located in the main portion of the trend, it is considered to be in an offset portion of the trend. Deposits that occur in the Southeastern Missouri District are—

Bonne Terre	Indian Creek
Boss-Bixby	Magmont
Brushy Creek Division	Milliken
Buick	Viburnum No. 28 and No. 29
Fletcher Division	Viburnum No. 35
Higdon	West Fork

Traditionally, these deposits have been assigned to the MVT classification. However, recent studies comparing mineralogic and geochemical characteristics of the MVT deposits suggest that the Missouri deposits may not belong to the MVT category (*21*). Deposits in the Viburnum Trend are the only MVT deposits in this study that contain recoverable amounts of silver. In addition, deposits in the Viburnum Trend and the Old Lead Belt are the only MVT sites studied that contain recoverable amounts of copper.

MONTANA

The zinc resources evaluated occur in five old mine areas approximately 2 km northwest of the Berkeley open pit copper mine. The five areas are the Alice, Anselmo, Badger, Lexington, and Mountain Con Mines, all of which were closed as of January 1, 1982. Although the Butte District is generally thought of as a copper district, 2.2 million t of zinc were produced from 1880 to 1972.

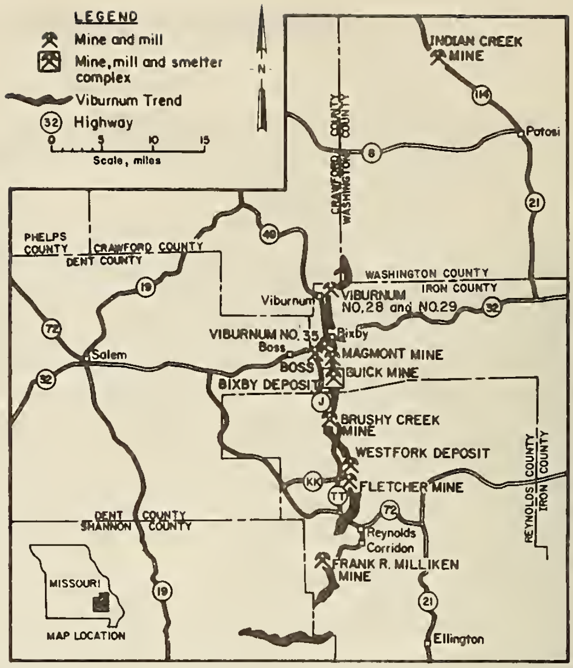

FIGURE C-1.—Locations of lead operations in the Viburnum Trend in Missouri.

The Late Cretaceous Butte Quartz Monzonite is the host rock for the deposits. Most of the resources occur within veins of the steeply dipping, east-west striking Anaconda vein system, with the mineralized portions of the veins extending for several hundred meters both horizontally and vertically.

The mineralized rock in the Butte District is concentrically zoned, with different minerals dominating each of the zones. Copper minerals are predominant in the central zone in the area of the Berkeley open pit copper mine, and zinc is dominant in the intermediate and peripheral zones. Lead, copper, and silver-bearing minerals also occur in the intermediate zone. The five evaluated mines are located in this intermediate zone.

NEVADA

The Ruby Hill deposit is located in the Eureka Mining District. The two most favorable stratigraphic horizons for mineralization in the district are the middle Cambrian Eldorado Dolomite and the middle to late Cambrian Hamburg Dolomite. Both dolomites host numerous replacement deposits. The area covered by the Ruby Hill evaluation is in between the Locan and Fad shafts. There, the Eldorado Dolomite is the host rock. Lead and zinc occur with associated gold and silver-bearing minerals, and the primary ores have been extensively oxidized by ground water.

The Ward District is composed mainly of easterly dipping sediments that are underlain and intruded by Tertiary quartz monzonites. All past production has been from the Ely Limestone, but recent exploration has been directed at the deeper rocks. Mineralized rock has been found in the upper and basal portions of the Joana Limestone, the Upper Guilmette Limestone, and the Guilmette-Quartz Monzonite contact. In addition to lead and zinc, low grade copper-molybdenum mineralized rock has been found in the quartz monzonite. The deposits are concentrated in two northwest-bearing trends, and they are both stratigraphically and structurally controlled and are usually manto shaped.

Two-thirds of the known resources in the district occur in the Upper Guilmette. Zinc, copper, lead, and silver-bearing minerals occur in the sedimentary deposits, but the ratios vary widely depending on horizon. The additional potential resources for the entire area are probably much larger than the demonstrated resources. Both of the Nevada sites occur in NMVT deposits.

NEW JERSEY

The Sterling Mine occurs in a district that consists largely of a series of Precambrian metasediments and metavolcanics intruded by a number of silicic igneous rocks (*26*). The sediments have been complexly folded and are synclinal in form. Minerals occur in certain limestone beds of the Franklin marble as NMVT replacement deposits. Mineralized rock may also occur in contact with pegmatite dikes elsewhere in the district. The mineral assemblage of the area is extremely unusual, and the major minerals are franklinite and willemite with minor zincite.

NEW MEXICO

The Pinos Altos deposit is located in the Silver City Mining District, an area that produced zinc, lead, copper, and gold in the past. Paleozoic and Cretaceous sedimentary rocks form a structural uplift that is cut by numerous igneous intrusives, the most important of which is the Pinos Altos quartz monzonite stock.

Most of the minerals occur in altered silty limestones and calcareous siltstones in the Pennsylvanian Syrena and Oswaldo Formations of the Magdalena Group. The NMVT deposit consists mainly of stratabound skarn replacement bodies in a kidney-shaped pattern, which trend in a northeasterly direction. Copper is dominant in the northern part of the deposit while lead, zinc, and silver are prominent in the southern part of the deposit.

NEW YORK

The Balmat and Pierrepont Mines are located in or near the Balmat-Edwards District, from which lead and zinc were first produced in the early 1900's. The district is located on a complex synformal structure, with lead and zinc minerals occurring in a zone that trends northeast-southwest. The NMVT stratiform deposits occur within certain marble and dolomite horizons of the metasedimentary Grenville Series. Minerals have been concentrated in the noses of folds and are generally conformable to the bedding.

Similar carbonate units and structures occur throughout the central part of the Adirondack lowlands (*28*). Hence, conditions are very favorable for the discovery of additional zinc sulfide deposits in the northwest Adirondacks.

PENNSYLVANIA

The Friedensville Mine is located in a small, folded and down-faulted block of early Paleozoic sediments of the Great Valley Province, which are surrounded by rocks of the New England crystalline uplift. Sphalerite occurs in gray crystalline dolomite in the lower portion of the Beekmantown Formation. The MVT mineralization is stratabound and occurs mainly as cementation in breccia bodies, but some replacement of adjacent strata also occurs.

TENNESSEE AND KENTUCKY

All of the deposits in Tennessee and Kentucky, with the exception of the Copperhill mines, are MVT deposits and occur in dolomite or limestone beds in either the Kingsport Formation and/or the Mascot Dolomite of the Cambro-Ordovician Knox Group.

The deposits evaluated occur in either the central Tennessee-Kentucky area, the Copper Ridge District, or the Mascot-Jefferson City District. Strata are generally horizontal in the central Tennessee-Kentucky region but dip moderately to the southeast in the other two districts. The mines and deposits evaluated for the Tennessee and Kentucky area are listed in table C-1 and their locations are shown on figure C-2.

The minerals generally occur in breccia bodies that are very complex and irregular in shape, forming a netlike pattern around islands of barren rock. Individual breccia bodies

Table C-1.—Primary zinc operations in Tennessee and Kentucky

	Map number[1]
Central Tennessee Zinc Region:	
Hartsville Area	1
Hartsville	2
Fountain Run	3
Carthage Property	4
Cumberland Property	5
Gordonsville-Elmwood	6
Stonewall	7
Gainesboro	8
Right Fork	9
East Gainesboro	10
Roaring River	11
Cub Creek	12
Cumberland	13
Cumberland Deposit	14
Burkesville Project	15
Pall Mall	16
Copperhill	17
Mascot-Jefferson City Zinc District:	
Immel	18
Beaver Creek	19
Young	20
New Market	21
Zinc Mine	22
Jefferson City Mine	23
Lost Creek	24
Coy	25
Copper Ridge District:	
Idol	26
Big War Creek	27

[1] Locations on figure C-2.

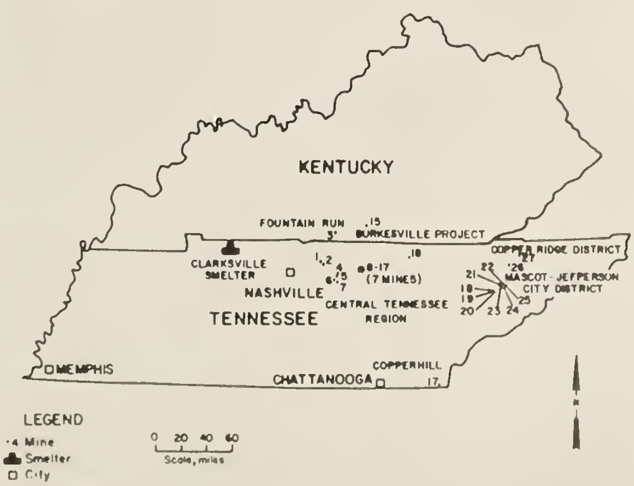

FIGURE C-2.—Locations of zinc operations in Tennessee and Kentucky.

located on different stratigraphic levels may be connected by vertical pipe-shaped breccia bodies (breakthrough ore bodies) also containing mineralized rock. All of the deposits are MVT with sphalerite as the major zinc mineral. Cadmium is also recovered at the producing operations (*21*).

The Copperhill mines are located in the Ducktown Mining District of Tennessee. For this investigation, the Boyd, Calloway, Cherokee, and Eureka Mines and the North and South Pits were combined and evaluated as 'Copperhill' because they would all utilize the Copperhill mill. Minerals occur in metamorphosed massive sulfide accumulations in metamorphosed interbedded graywackes and mica schists in the Late Precambrian Copperhill Formation of the Great Smoky Group. These rocks have been folded and faulted. There are two or possibly three series of beds that are favorable for mineralization, and many of the deposits occur where the favorable sediments have been thickened by folding. The Copperhill mines are in NMVT deposits.

The minable ore deposits of the Ducktown area can be assigned to three general groups: northwestern, southeastern, and central. The Calloway Mine belongs to the southeastern group, while the Eureka, Boyd, and Cherokee Mines belong to the central group. The ore bodies of the first two groups are high in copper and zinc, while those of the central group are higher in sulfur and iron. All the deposits contain iron, copper, and zinc, with minor gold, silver, and galena (*26*).

UTAH

The Ontario Mine is located in the Park City Mining District. The district is developed in an area of approximately 100 sq km on a northward-plunging anticline and syncline of Paleozoic and Mesozoic sediments. Intrusive and extrusive igneous rocks are also present throughout the district and were important to the deposition and control of mineralization. The ore bodies occur as both bedded replacement and vein deposits, of which the replacement deposits have the highest lead and zinc content. The district only contains NMVT deposits.

Current interest centers around the replacement deposits, which occur most often in limestone beds of the Paleozoic Humbug, Doughnut, Deseret, Weber, Park City, and the Mesozoic Thaynes Formations. The ore bodies at the Ontario Mine occur most frequently in the Humbug Formation, to a lesser extent in the Doughnut and Deseret Formations, and consist of zinc, lead, and silver-bearing minerals.

On a district-wide scale, most of the individual ore bodies are quite small, and many of the mines intersect numerous ore bodies. Ore type is not uniform throughout the district. "The silver-rich ores are far more commonly developed in the northern part of the district, while those rich in gold and copper occur in the lower reaches of the fissure systems to the south" (*26*). These metals add significant value to the lead-zinc ore. Mineralization at the Ontario Mine falls between these two extremes.

WASHINGTON

The Washington Zinc Unit, formerly known as the Van Stone Mine, and the Metaline District lie within the southern portion of the Kootenay arc, a narrow belt of folds and faults extending southwest from British Columbia into Washington. The MVT deposits occur as both concordant and discordant mineralized bodies in the Middle Cambrian Metaline Limestone. Minerals occur in the middle dolomite unit of the Metaline limestone at the Washington Zinc Unit mine and in the Josephine horizon in the Metaline District.

The deposits of the Metaline District occur within a graben block of about 120 sq km in size. Although the replacement deposits occur throughout the graben area, a greater number of them occur in the southern portion of the district. The known resources for the entire Metaline District were evaluated.

The deposits are generally found in silicified brecciated dolomite, in the axes of folds, and in highly fractured zones. The deposits are very irregularly shaped but are generally conformable to the bedding. Individual ore bodies range in size from a few to several hundred meters in length and width.

WISCONSIN

The Shullsburg, Bearhole, Elmo No. 3, and Crawhall Mines are located in the Upper Mississippi Valley Zinc-Lead District. The district encompasses about 6,400 sq km, predominantly in southwestern Wisconsin. Most of the past production has come from the Platteville-Galena-Shullsburg area. Minerals occur in several different horizons of the Paleozoic sedimentary rocks, the most important of which are the Middle Ordovician Decorah, Galena, and Platteville Formations. Most of the lead production has come from the Galena.

These four sites all occur in MVT deposits, where the majority of the minerals occur in fractures and open spaces. Ore bodies that are more disseminated in character occur in the northern part of the district, while vein deposits are more common in the southern part of the district. Mineralized bodies are separated from each other by large sections of barren rock. Mineralized ratios change with locale, and zinc, lead, or barite may each be the dominant mineral of a particular deposit.

The Crandon and Pelican River massive sulfide deposits occur in a belt of metamorphosed Precambrian volcanic rocks that strike east-west across Wisconsin. Recent exploration has been concentrated in a 100-km-wide greenstone belt stretching about 350 km from Ladysmith to Pembine (*29*). The Flambeau-Ladysmith copper deposit also occurs in this belt.

Both the Crandon and Pelican River deposits are NMVT deposits that are Precambrian stockworks, with minerals occurring in a series of closely spaced stringers. The Crandon deposit has two entirely distinct ore types: stringer ore, which contains copper with minor zinc, and massive sulfide ore, which contains zinc-copper-lead mineralization. Both ore types occur separately and will also be mined and treated separately. In addition, small amounts of gold and silver occur.

Further exploration in the greenstone belt could yield substantial additional resources of copper, lead, or zinc. The lack of nearby smelting and refining capacity has hampered development, and exploration and development work has been difficult in recent years owing to the environmental climate in the State.